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Task demands and representation in long-term repetition priming

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The effects of task demands on the representation of letter strings in long-term repetition priming (LTRP) were explored in two lexical decision experiments. The stimuli in both experiments were words and nonwords, some presented horizontally and some vertically. The only difference between the two experiments was the response required by the participant. In Experiment 1, the participants pressed one of two buttons, indicating whether or not a given stimulus was a word. In Experiment 2, the participants pressed one of four buttons, indicating both the lexical status and the orientation of a given stimulus. The results were that in Experiment 1, LTRP was not disrupted by a change in stimulus orientation, whereas in Experiment 2 it was, suggesting that the nature of the stimulus representation utilized in LTRP is partially dependent on the demands of the task.

Long-term repetition priming (LTRP) occurs when the repetition of a stimulus improves performance on a task, with several trials (or more) separating the repetitions. Presumably, for repetition priming to occur, either a representation already existing in memory is being influenced (e.g., a lowering of the threshold for activation; Anderson, 1983; MacKay, 1982) or a memory trace is being created each time the stimulus is presented (e.g., Feustel, Shiffrin, & Salasoo, 1983; Logan, 1988, 1990, 1992; Salasoo, Shiffrin, & Feustel, 1985). Although there is considerable debate regarding the processing mechanisms that drive LTRP, less attention has been paid to the issue of representation. That is, what is the nature of the cognitive representation of stimuli utilized so that repetition priming occurs? In this paper, I suggest that there is not a single answer to this question, because even within the constraints of a lexical decision task, the answer is based not just on the nature of the stimuli, but also on *what* it is participants are asked to do with the stimuli presented to them.

Lexical decision tasks are among the most commonly used paradigms for exploring repetition priming in general and LTRP in particular (e.g., Grant & Logan, 1993; Hintzman, 1976; Kersteen-Tucker, 1991; Logan, 1988; McKone, 1995; Ratcliff, Hockley, & McKoon, 1985). In lexical decision tasks, participants are asked to indicate as quickly as possible whether or not a given letter string is a word. This is a relatively simple exercise for a literate adult, yet participants improve (get faster) with repetition. The decrease in response time (RT) owing to repetition (repetition priming) is more than a generalized practice effect, because to a large degree it is limited to the specific stimuli being repeated (e.g., Forbach, Stanners, & Hochhaus, 1974; Logan, 1988).

Repetition priming can be used to gain insight about how stimuli are represented. If a stimulus is presented in one form at Time 1 (e.g., uppercase letters) and in another form at Time 2 (e.g., lowercase letters), the effect of changing the stimulus on repetition priming can give us a clue as to how the stimuli are represented. For example, if repetition priming were to occur regardless of changes in letter case, this would imply that the representation does not capture the simple physical features of the stimulus. To date, much of the repetition priming research has been focused on the effects of stimulus type or repetition delay on lexical decision performance. This approach has been fruitful and has led researchers to suggest two potential types of representations: an abstractionist *lexical* representation and an episodic stimulus-based representation (e.g., Brown & Carr, 1993; Carr, Brown, & Charalambous, 1989; Carr et al., 1992; Jacoby & Brooks, 1984; Logan, 1988, 1990). Tenpenny's (1995) thorough review summarizes these two positions and the evidence in favor of each (see also Brown & Carr, 1993).

This paper focuses on LTRP and the nature of the cognitive representations of stimuli that allow priming to occur. The task reported here was designed to produce LTRP and is similar to one used by Logan (1988, Experiment 1) to produce strong LTRP effects.

Logan (1988) reported the results of a lexical decision task in which words and nonwords were presented in

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blocks of trials. In one condition, the letter strings were new in each block; in another condition, the same letter strings were presented across blocks. The critical finding was that RT decreased with practice in both conditions but that the effect of practice was substantially greater for the condition in which the letter strings were repeated. This additional benefit (beyond the general practice effect) is stimulus specific (i.e., LTRP). Logan was primarily concerned with the processes that drive LTRP and demonstrated that the RT pattern associated with LTRP conforms to a power law that is consistent with a general theory of automaticity that is based on episodic traces.

The present experiments focus not on the process(es) through which the purported memory traces are created (or activated), but on the nature of the memory representations themselves. That is, in a lexical decision task that produces LTRP, is the nature of the stored representation of the stimulus such that simple physical features (e.g., orientation) are captured, or is the representation more abstract? There is a limited amount of data that addresses this issue, most of which deals with only one repetition of the stimuli (e.g., Brown & Carr, 1993; Scarborough, Cortese, & Scarborough, 1977) . For example, Scarborough et al. reported data from a lexical decision task in which each stimulus was repeated once in the experiment. Scarborough et al. found a repetition effect on RT for words and nonwords in a lexical decision task in which the time between stimulus repetition was as long as 2 days. The relevant result for the present purposes is that they found that the size of the repetition effect was independent of whether the repeated stimulus was presented in the same or a different letter case than the original stimulus. Although they used only one repetition, on the basis of these data, Scarborough et al. argued that the nature of stimulus representation utilized in LTRP is insensitive to letter case and thus consistent with a more abstract representation that does not contain basic featural information. The primary purpose of Experiment 1 was to provide a strong test of the hypothesis that participants use an abstract representation of letter strings and that it is this representation that produces a strong priming effect across dozens of trials.

The logic underlying the two reported experiments assumes that the nature of the representation involved in LTRP can be determined by manipulating characteristics of the stimulus display. Orientation of the stimuli is manipulated, and if these changes in orientation have an effect on the course of LTRP, we can assume that the representation involved captures this physical aspect of the stimuli. On the other hand, if a more abstract representation is generated and this representation forms the basis of LTRP, manipulations of orientation should not influence the LTRP effect.

EXPERIMENT 1

As was discussed above, Experiment 1 was designed to determine whether orientation information is maintained as part of the stimulus representation that allows LTRP to occur. In each of six blocks, 120 letter strings were presented for a lexical decision. Half of the strings formed words, and half formed pseudowords (i.e., pronounceable nonwords). In addition, half of the strings were presented in a horizontal orientation, and half were presented in a vertical orientation. One third of the words and nonwords presented in a block appeared for the first and only time and thus were new to the participant (*new*). This condition served as a baseline to compare potential repetition effects against. One third of the stimuli were repeated once per block in the same orientation (*repeated*), and one third were repeated once per block in the same orientation for the first five blocks and then in the opposite orientation for the sixth block (*test*).

If the orientation of the letter string is part of the representation, performance on the last block in the *test* condition (in which orientation is switched relative to the previous five presentations) should be significantly different from performance on the last block in the *repeated* condition (in which orientation is held constant across all six presentations). Alternatively, if orientation is not a critical component of the representation, performance on the last block should be similar for the *test* and the *repeated* conditions.

Method

Participants. Sixteen Colgate University undergraduates participated in one 55-min session in partial fulfillment of a participation requirement for an introductory psychology course. All the participants reported having either normal or corrected-to-normal vision and normal color vision and stated that they were native English speakers.

Apparatus and Stimuli. A Dell microcomputer with a Cyber-Research CYCTM-05X timer/counter card provided millisecond timing and controlled stimulus presentation (via a standard 17-in. VGA monitor) and response acquisition (via a button box). The stimuli were displayed in text mode. The responses were made on a two-button response box with horizontally arranged buttons.

Two lists were created, one composed of words and one of pronounceable nonwords. The word list consisted of four-letter common nouns selected from the Kučera and Francis (1967) frequency norms, ranging in absolute frequency from 7 to 900 per million (similar to the range used in Logan, 1988). The nonword list was created by replacing one or two letters of each word in the word list with another letter, creating a nonword. Three independent observers judged the pronounceability and lexical status of each item in both lists. Only those stimuli that all three observers agreed on were included in the final lists of 577 words and 577 nonwords.

Procedure. On each trial, a four-letter stimulus was presented until a response was made or 1,500 msec had elapsed. The intertrial interval was 1,500 msec. The participants were required to make a buttonpress indicating whether the stimulus was or was not an English word. The computer emitted a 450-Hz tone for 50 msec, followed by a 300-Hz tone for 150 msec in response to an error. Half of the participants were instructed to press the right button in response to a word and the left button in response to a nonword. The other half of the participants were given the opposite assignment. RT and error rate were the dependent variables.

Design. Lexical status (word vs. nonword) and condition (repeated vs. new vs. test) were varied within participant and block. For each participant, the word and nonword stimuli were drawn randomly, without replacement, from the word and nonword lists, respectively.

Ten words and 10 nonwords were associated with each orientation and condition within each block (i.e., 10 vertical words, 10 horizontal words, 10 vertical nonwords, and 10 horizontal nonwords for each of the three conditions, for 120 letter strings in each block). A novel set of words and nonwords were used in the new condition for each block. Within a block of trials, the words and nonwords from each condition were presented once, in a different random order for each participant.

The participants performed in a practice block of 36 trials, followed by six blocks of 120 trials. The purpose of the practice block was to familiarize the participants with the task, thereby minimizing generalized learning effects. Each block began with two practice trials, and errors were followed by a recovery trial. The data from the practice block, preblock practice trials, and recovery trials were not analyzed. The stimuli used in the practice block, preblock practice trials, and recovery trials were drawn separately and were therefore distinct from the stimuli used in the blocks to be analyzed.

Results and Discussion

A 2 × 2 × 6 repeated measures analysis of variance (ANOVA) was performed on the mean RT data from each participant with lexical status (word and nonword), condition (new, repeated, and test), and block (1–6) as factors. All the tests reported statistically significant were at the $p < .05$ level. Mean RTs as a function of condition and block are shown in Figure 1.

All three main effects were significant [lexical status: $F(1,15) = 102.53$, $MS_e = 6,473.48$; condition: $F(2,30) = 53.29$, $MS_e = 1,529.75$; block: $F(5,75) = 4.55$, $MS_e = 7,648.61$], but the effect of interest concerns the significant interaction of block and condition [$F(10,150) = 2.41$, $MS_e = 1,198.29$]. The interaction is consistent with the argument that there were qualitatively different learning effects for the different conditions (as can be seen on visual inspection of Figure 1). The interaction between lexical status, block, and condition was not significant [$F(10,150) = 1.83$, $MS_e = 890.14$], confirming that the interaction between block and condition was not significantly different for words and nonwords.

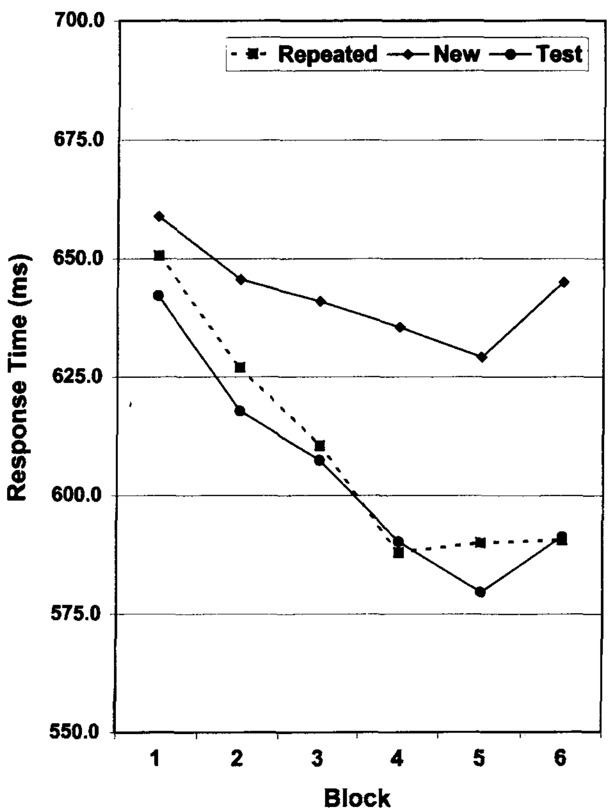

Figure 1. Mean reaction time as a function of block by condition (repeated, new, and test) for Experiment 1.

Error rates by condition and block are contained in Table 1. The overall error rate was 4.1%, and errors were positively correlated with RT, indicating the absence of a speed–accuracy tradeoff. Error rates were analyzed with a two-factor (condition and block) repeated measures ANOVA. Consistent with the RT data, there was a main effect of block [$F(5,75) = 3.11$, $MS_e = 12.99$] and a significant main effect of condition [$F(2,30) = 25.01$, $MS_e = 17.73$]. Unlike the RT data, however, there was not a significant interaction between block and condition [$F(10,150) = 1.45$, $MS_e = 9.22$]. Taken together, the RT and error rate data are consistent with the argument that there was significant learning and that this learning was item specific, in that it was maximal in the conditions in which the same stimuli were presented across blocks of trials.

What do the results tell us about representation? The critical comparisons for Experiment 1 involve the responses from the sixth block for the three conditions. Planned comparisons for the three conditions in the sixth block were evaluated utilizing two-tailed paired-comparison *t* tests. What should the data look like if orientation is *not* a fundamental part of the representation utilized in LTRP? If this were the case, there would be no functional difference between the *repeated* and the *test* conditions, and performance on the last block in those conditions should be similar (and if there are repetition effects, both should be different from the *new* condition). On the other hand, if orientation *is* a fundamental part of the representation of interest, the presentation of a *test* stimulus in the sixth block should be qualitatively different from the sixth presentation of a *repeated* stimulus, and performance should differ between these two conditions. In fact, RT performance in the *repeated* and the *test* conditions was not significantly different [591 vs. 591 msec; $t(15) < 1$, $SE = 8.36$, $CI = -18.59$–17.06], and both conditions differed significantly from the *new* condition [645 msec, $t(15) = 9.3$, $SE = 5.84$, $CI = 42.06$–66.97, and $t(15) = 7.7$, $SE = 6.97$, $CI = 38.89$–68.61, respectively].[1] This same pattern is seen in the error rates, which were not significantly different between the *repeated* and the *test* conditions [1.56% vs. 1.87%; $t(15) < 1$, $SE = 0.75$, $CI = -1.92$–1.29] but were significantly different between each of these conditions and the new condition [5.60%; $t(15) = 4.4$, $SE = 0.93$, $CI = 2.06$–6.01, and $t(15) = 3.2$, $SE = 1.16$, $CI = 1.26$–6.19, respectively].

In summary, the RT and error rate data from Experiment 1 suggest that seeing a stimulus repeated for the sixth time in a different orientation from the five previous pre-

Table 1
Experiment 1 Error Rates by Condition and Block

	Block					
Condition	1	2	3	4	5	6
New	6.4	5.6	7.7	6.8	7.0	5.6
Repeated	5.2	3.3	3.1	2.2	2.5	1.6
Test	4.9	3.1	3.4	1.4	1.3	1.9

sentations (i.e., a *test* condition stimulus) is not statistically different from the sixth presentation of a stimulus in the same orientation for all the presentations (i.e., a *repeated* condition stimulus). These results are consistent with a representation that does not incorporate the physical features of letters. Using this same paradigm, but manipulating color and font instead of orientation, produces the same pattern of results (Johnson, 1996). Taken together, these data suggest that for LTRP, basic physical features of the stimulus are not encoded in the pertinent memory representations, consistent with an abstract representation.

In addressing the important question of the nature of stimulus representation in LTRP, Experiment 1 indicates that orientation does not play a role. When combined with other reported data (e.g., Carr et al., 1989; Johnson, 1996; Scarborough et al., 1977), a reasonable argument could be made for an abstract representation that is independent of the basic physical features of the stimulus. However, one critical question that is left out of this approach concerns the demands on the participant at the time of stimulus encoding. Before making claims about *the* nature of *the* representation, it seems reasonable to ask to what extent the internal representation used by the participant depends on the particular task demands. That is, does the same physical stimulus get represented in different ways, depending on the needs of the participant? Recent work by Logan and colleagues (i.e., Logan & Etherton, 1994; Logan, Taylor, & Etherton, 1996) suggests that what is represented is dependent not just on the stimulus, but on the demands of the task as well.

EXPERIMENT 2

In Experiment 1, the participant's task was to indicate *word/nonword*. The participants were surely aware that stimulus orientation varied but was not task relevant. If the participants had no reason to attend to orientation because it was irrelevant to their response, why should they waste cognitive resources representing something for which they had no use? On the other hand, if there is only a single type of representation that is utilized in LTRP and that representation does not capture orientation, task demands, by definition, cannot influence the nature of the representation used.

The stimuli for Experiment 2 were identical to those used in Experiment 1. The only change was the nature of the response required of the participant. Instead of the *word/nonword* two-button response in Experiment 1, in Experiment 2 there were four responses: *horizontal word*, *vertical word*, *horizontal nonword*, and *vertical nonword*. Thus, the stimuli were identical, but the demands on the participant made orientation relevant to the task.

Method

Participants. Twenty-one Colgate University undergraduates participated in one 55-min session in partial fulfillment of requirements for an introductory level psychology course. All the participants reported having either normal or corrected-to-normal vision, stated that they were native English speakers, and had not participated in Experiment 1.

Apparatus and Stimuli. The equipment and stimuli were the same as those in Experiment 1, except that the button box had four buttons (two in a top row, two in a bottom row).

Procedure. The procedure was the same as that in Experiment 1, except that the participants were instructed to press one of four buttons, indicating the orientation and lexical status of a stimulus (e.g., separate buttons for horizontal word, vertical word, horizontal nonword, and vertical nonword).

Design. The design was the same as that in Experiment 1.

Results and Discussion

The results of Experiment 2 are shown in Figure 2. A three-factor (lexical status, condition, and block) repeated measures ANOVA was performed on the mean RT data from each participant, with the overall results paralleling those from Experiment 1. Again, all three main effects were significant [lexical status: $F(1,20) = 87.50$, MS_e =

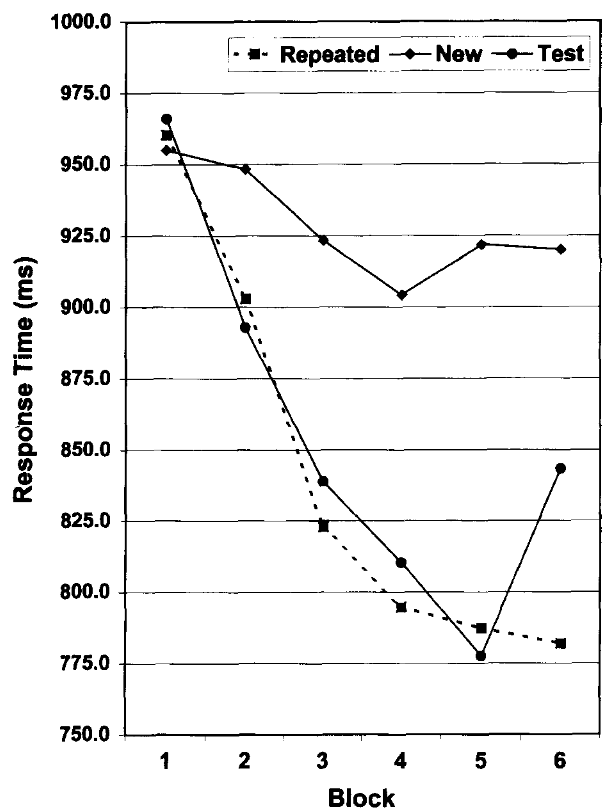

Figure 2. Mean reaction time as a function of block by condition (repeated, new, and test) for Experiment 2.

34,695.27; condition: $F(2,40) = 43.36$, $MS_e = 12{,}810.20$; block: $F(5,100) = 12.89$, $MS_e = 26{,}158.41$], and there was a significant interaction between block and condition [$F(10,200) = 7.12$, $MS_e = 6{,}357.74$], demonstrating that the priming effect was not the same for the three conditions. The interaction between lexical status, condition, and block was not significant [$F(10,200) < 1$], again indicating that the differential effects of practice on conditions did not vary on the basis of lexical status.

Error rates by condition and block are contained in Table 2. The overall error rate was 4.4%, and errors were positively correlated with RT, indicating the absence of a speed–accuracy tradeoff. Error rates were analyzed with a two-factor (condition and block) repeated measures ANOVA. Paralleling the RT data, there were significant main effects of block [$F(5,100) = 13.13$, $MS_e = 18.4$] and condition [$F(2,40) = 9.75$, $MS_e = 17.4$], along with a significant interaction between block and condition [$F(10,200) = 3.17$, $MS_e = 8.78$].

As in the first experiment, in Experiment 2 the critical comparisons involve the responses from the sixth block for the three conditions. Planned comparisons for the three conditions for the sixth block were evaluated utilizing two-tailed paired-comparison t tests. Unlike the results of Experiment 1, here, performance as measured by RT in the *repeated* and *test* conditions *was* significantly different [782 vs. 843 msec, $t(20) = 3.847$, $SE = 15.98$, $CI = 28.12–94.78$], and both conditions differed significantly from the *new* condition [920 msec, $t(20) = 5.75$, $SE = 24.02$, $CI = 88.08–188.30$, and $t(20) = 3.35$, $SE = 22.90$, $CI = 28.97–124.50$, respectively]. Likewise, the pattern for the error rates differed qualitatively from those in Experiment 1. The error rates were significantly different between the *repeated* (1.31%) and the *test* (5.71%) conditions [$t(20) = -4.093$, $SE = 1.08$, $CI = 2.16–6.65$] and the *repeated* and the *new* (5.00%) conditions [$t(20) = 2.87$, $SE = 1.29$, $CI = 1.01–6.37$]. There was not a significant difference in error rate between the *test* and the *new* conditions [$t(20) < 1$, $SE = 1.57$, $CI = -4.00–2.57$].

In contrast to Experiment 1, the data from Experiment 2 suggest that orientation *was* an important aspect of the representation of interest. Here, participants behaved differently between the *repeated* and *test* conditions. Changing the demands on the participant, while keeping the stimuli the same, leads to a different answer to the representation question. The results from Experiment 2, in which participants had to attend to orientation in order to respond, are consistent with a representation utilized in LTRP of lexical decision that is sensitive to the orientation of the letter strings. Note, however, that although the results show a sensitivity to orientation, there were some savings in the *test* condition, as compared with the *new* condition. This last result suggests that orientation is not the only aspect of the stimulus that is accessing the representation and driving the priming process.

Table 2
Experiment 2 Error Rates by Condition and Block

	Block					
Condition	1	2	3	4	5	6
New	7.9	6.7	5.6	4.6	4.0	5.0
Repeated	7.9	4.4	2.3	2.0	2.1	1.3
Test	8.6	3.6	3.0	2.0	2.5	5.7

GENERAL DISCUSSION

Experiment 1 was designed to address an important and seemingly straightforward problem: Given that we know that LTRP utilizes memory representations, can we determine what information is contained in these representations? The data seemed to suggest that orientation was not captured in the representation that drives LTRP in this paradigm. Combined with other findings (e.g., Caramazza & Hillis, 1990; Johnson, 1996; Rapp & Caramazza, 1991; Scarborough et al., 1977), a reasonable explanation would be that LTRP in lexical decision is based on an abstract representation that does not contain information regarding the basic physical features of the stimulus.

In Experiment 2, orientation was made task relevant, and the same stimuli produced qualitatively different results from those obtained in Experiment 1. Taken alone, the results of Experiment 2 would suggest that the representation utilized by the processes that produce LTRP *does* capture basic physical features of the stimulus, including orientation. Taken together, however, the results of Experiments 1 and 2 suggest that there is not a fixed representational type that drives LTRP in lexical decision.

In retrospect, these data make sense when considered in terms of cognitive efficiency. In order for a cognitive system to maximize efficiency, how a stimulus is represented should greatly depend on what the demands are on the system. If the task at hand requires knowledge of color, orientation, spatial location, and so forth, this information should be stored in order to improve performance in the future. On the other hand, if performing the current task (and tasks like it from previous experience) does not require knowledge of basic physical features, it is not efficient to take the time and storage resources to capture something that is not behaviorally relevant. This concept is similar to *transfer-appropriate processing*, as originally proposed by Morris, Bransford, and Franks (1977), who, on the basis of a series of three experiments using a factorial manipulation of task and test type (e.g., rhyming and semantic), argued that "the value of particular acquisition activities must be defined relative to particular goals and purposes" (p. 523).

One class of theories proposed to explain repetition priming effects has been referred to by Brown and Carr (1993) as *strongly episodic*. This approach (e.g., Jacoby and Brooks, 1984; Masson, 1986) explains repetition effects on the basis of retrieval of prior episodes, where the retrieval process (independent of task demands) is dependent on the detailed physical attributes of stimuli. This approach explains the data from Experiment 2 quite well: When orientation was switched, the priming diminished because the stimuli did not match stored episodes.

Unfortunately (for this account of the data), in Experiment 1, stimuli that did not change physically and stimuli that did both showed large (and not statistically different) priming effects. These results are inconsistent with episode retrieval theories, which rely solely on a strong match between the specific physical features of a stimulus and the specific stimulus features stored as part of an episode.

The abstractionist approach used to explain repetition effects is based on abstract representations (e.g., Morton, 1969). Here, words have a generic representation that is activated independent of the specific physical (i.e., surface) features of the stimulus. These representations have *activation values*, and when a threshold is reached, identification can be made. The presentation of a stimulus increases the activation value of its corresponding abstract representation in memory. Repetition effects occur when the activation of a memory representation has not decayed to baseline before the next repetition. The results of Experiment 1 are well explained by this class of theory: Changing orientation did not affect priming, because the abstract nature of the representation was orientation independent. On the other hand, the results of Experiment 2 are at odds with the strong form of the abstractionist approach, because priming effects were different for untransformed and transformed stimuli. This result would not be expected if the representations are always abstract and independent of such features as orientation.

There is a third class of theories, those that Brown and Carr (1993) consider to be *weakly episodic*, that can account for repetition effects and the present results. An example is Logan's (1988, 1990, 1992) instance-based theory of automaticity. Although the instance-based theory is primarily concerned with the *processes* that drive automaticity, the very nature of an instance is that it is a memory trace that contains information regarding the stimulus (i.e., a representation). Logan and Etherton (1994), as well as Logan et al. (1996), have argued that the contents of an instance are subject to attention at the time of encoding (the *attention hypothesis*). The idea is that the contents of a memory trace are dependent on the aspects of a stimulus that are attended to during learning. For example, Logan and Etherton found that the cooccurrences of words in a display were not encoded in a word categorization experiment under focused attention conditions (in which only one of the words was attended to) but were under divided attention and dual-task conditions (in which both words were attended to). Thus, they found evidence that the same stimuli were represented differently, depending on the task demands on the participant. Generally speaking, this is the same phenomenon as that found in the present experiments.

The attention hypothesis could account for the data here simply by assuming that, in Experiment 1, the participants did not attend to orientation because it was not relevant to the task and that, in Experiment 2, orientation was attended to because it was task relevant. The hypothesis would predict that the memory traces created in response to the stimuli in Experiment 1 would not contain orientation information and that those created in response to the stimuli in Experiment 2 would. This prediction is consistent with the data obtained.

One limitation of the present research concerns the distinction between what a representation contains (i.e., what was encoded) and how information from a representation is retrieved.[2] Whereas the above explanations focused on the content of the representations, an alternative account is that the representations are constant across tasks but that retrieval strategies change. The argument is that both the physical features of the stimulus and an abstract conceptualization are always part of the representation. Episodic retrieval can then be based on either component, depending on task. This alternative approach does not alter the relationship between the present experiments and the strongly abstractionist and strongly episodic theories. By definition, these theories are inconsistent with a representation that is both physically specific and abstract. However, a weakly episodic account would allow an episode (or *instance*) to contain multiple representations. Although this explanation relies on a cognitively less efficient approach (there are two stimulus representations stored with each episode), the present experiments cannot rule it out. Studies are underway to help distinguish between the encoding and the retrieval explanations.

In addition to the issue of encoding and retrieval, an interesting question for further research concerns nonstring stimuli. Given that LTRP occurs with a variety of stimuli besides letter stings (e.g., polygons, Kersteen-Tucker, 1991; alpha-numeric operations, Logan, 1988, 1990, 1992), are there similar task-specific physical dependencies? If efficiency considerations drive the results reported here, we would expect to see similar task-dependent effects with other stimuli and in other experimental paradigms.

Perhaps obviously, a complete explanation of any cognitive phenomenon requires an understanding of both process and representation. Although the best explanation for the present results seems to be weakly episodic theories, the empirical findings constrain *any* theory that attempts to account for LTRP, by suggesting that representation is affected in part by task demands.

REFERENCES

Anderson, J. R. (1983). *The architecture of cognition*. Cambridge, MA: Harvard University Press.

Brown, J. S., & Carr, T. H. (1993). Limits on perceptual abstraction in reading: Asymmetric transfer between surface forms differing in typicality. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **19**, 1277-1296.

Caramazza, A., & Hillis, A. E. (1990). Levels of representation, coordinate frames, and unilateral neglect. *Cognitive Neuropsychology*, **7**, 391-445.

Carr, T. H., Brown, J. S., & Charalambous, A. (1989). Repetition and reading: Perceptual encoding mechanisms are very abstract but not very interactive. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **15**, 763-778.

Carr, T. H., Dagenbach, D., VanWieren, D., Carlson Radvansky,

L. A., Alejano, A. R., & Brown, J. S. (1992). Acquiring general knowledge from specific episodes of experience. In C. Umiltà and M. Moscovitch (Eds.), *Attention and performance XV: Conscious and nonconscious information processing* (pp. 697-724). Cambridge, MA: MIT Press, Bradford Books.

Feustel, T. C., Shiffrin, R. M., & Salasoo, A. (1983). Episodic and lexical contributions to the repetition effect in word identification. *Journal of Experimental Psychology: General*, **112**, 309-346.

Forbach, G. B., Stanners, R. F., & Hochhaus, L. (1974). Repetition and practice effects in a lexical decision task. *Memory & Cognition*, **2**, 337-339.

Grant, S. C., & Logan, G. D. (1993). The loss of repetition priming and automaticity over time as a function of degree of initial learning. *Memory & Cognition*, **21**, 611-618.

Hintzman, D. L. (1976). Repetition and memory. In G. H. Bower (Ed.), *The psychology of learning and motivation* (pp. 47-91). New York: Academic Press.

Jacoby, L. L., & Brooks, L. (1984). Nonanalytic cognition: Memory, perception, and concept learning. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 18, pp. 1-47). New York: Academic Press.

Johnson, D. N. (1996, October). *The representation of letter strings as assessed by long-term repetition priming*. Paper presented at the 37th Annual Meeting of the Psychonomic Society, Chicago.

Kersteen-Tucker, Z. (1991). Long-term repetition priming with symmetrical polygons and words. *Memory & Cognition*, **19**, 37-43.

Kučera, H., & Francis, W. N. (1967). *Computational analysis of present-day American English*. Providence, RI: Brown University Press.

Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological Review*, **4**, 492-527.

Logan, G. D. (1990). Repetition priming and automaticity: Common underlying mechanisms? *Cognitive Psychology*, **22**, 1-35.

Logan, G. D. (1992). Shapes of reaction-time distributions and shapes of learning curves: A test of the instance theory of automaticity. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **18**, 883-914.

Logan, G. D., & Etherton, J. L. (1994). What is learned during automatization? The role of attention in constructing an instance. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **20**, 1022-1050.

Logan, G. D., Taylor, S. E., & Etherton, J. L. (1996). Attention and the acquisition and expression of automaticity. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **22**, 620-638.

MacKay, D. G. (1982). The problem of flexibility, fluency, and speed–accuracy trade-off in skilled behavior. *Psychological Review*, **89**, 483-506.

Masson, M. E. J. (1986). Identification of typographically transformed words: Instance-based skill acquisition. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **12**, 479-488.

McKone, E. (1995). Short-term implicit memory for words and nonwords. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **21**, 1108-1126.

Morris, C. D., Bransford, J. D., & Franks, J. J. (1977). Levels of processing versus transfer appropriate processing. *Journal of Verbal Learning & Verbal Behavior*, **16**, 519-533.

Morton, J. (1969). Interaction of information in word recognition. *Psychological Review*, **76**, 165-178.

Rapp, B. C., & Caramazza, A. (1991). Spatially determined deficits in letter and word processing. *Cognitive Neuropsychology*, **8**, 275-311.

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.

Salasoo, A, Shiffrin, R. M., & Feustel, T. C. (1985). Building permanent memory codes: Codification and repetition effects in word identification. *Journal of Experimental Psychology: General*, **114**, 50-77.

Scarborough, D. L., Cortese, C., & Scarborough, H. S. (1977). Frequency and repetition effects in lexical memory. *Journal of Experimental Psychology: Human Perception & Performance*, **3**, 1-17.

Tenpenny, P. L. (1995). Abstractionist versus episodic theories of repetition priming and word identification. *Psychonomic Bulletin & Review*, **2**, 339-363.

NOTES

1. The 95% confidence interval of the difference.
2. I thank Gordon Logan for pointing out this limitation.

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