

Procedural Learning:

2. Intertrial Repetition Effects in Speeded-Choice Tasks

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Previous research has demonstrated that subjects' responses in a speeded-choice task are affected by the sequence of stimuli and responses. Generally, responses are faster when the same stimulus is repeated. There is disagreement in the literature concerning whether or not this effect represents a speedup of perception, response execution, or central stages of processing. The first 5 experiments reported here demonstrate that the effect is quite stimulus specific: A succession of different stimuli that call for the same response produces little repetition benefit, unless the stimuli differ only in very superficial ways (e.g., in color). Increasing the intertrial interval from 100 ms to 1000 ms attenuates these repetition effects only slightly. These results would be consistent with a perceptual locus for the repetition effect, but Experiment 6 shows that if the response mapping changes from trial to trial, the advantage for stimulus repetitions is abolished. The results indicate that locus of the repetition effect is at the stage of response selection. However, the stimulus specificity of the effects indicates that immediate repetitions produce or strengthen transient links that "shortcut" the response-selection stage. By contrast, the results of Pashler and Baylis (1991) indicate that practice primarily strengthens response selection at the categorical level rather than shortcutting it. One implication of the results is that the practice effect is not created simply by the accumulation of the traces responsible for repetition effects.

When subjects perform the same task over the course of many trials, repetition of the same stimulus affects performance usually in a beneficial way. Effects of this sort can be observed in tasks as diverse as semantic categorization (Monsell, 1987), lexical decision (Scarborough, Gerard, & Cortese, 1979), and speeded-choice tasks (Smith, 1968). Obviously, however, such repetition effects may have different causes in different situations. The purpose of the present article is to examine the repetition effect in one particular situation: speeded-choice tasks in which subjects make one of several different responses depending on the identity of a simple stimulus. Speeded-choice tasks provide a simple model for the many human skills that require selection and production of a response that bears only an arbitrary relationship to the stimulus that triggers it. For that reason alone, factors like repetition, which powerfully modulates performance in such tasks, are of some inherent interest. In addition, however, we attempt here to address a basic question about procedural learning that has not been previously considered: whether the repetition effects reflect exactly the same underlying learning changes as the longer term practice effects observed in the same paradigms. In the preceding article, we examined prac-

tice effects in tasks virtually identical to these (Pashler & Baylis, 1991), and the manipulations included here deliberately parallel those in the preceding article. The goal of this parallel attack is to determine how practice and repetition effects are related to each other as well as to learn more about the locus of the repetition effect itself.

Repetition Effects in Speeded-Choice Tasks

When the same stimulus is repeated in a speeded-choice task, responses are faster than on nonrepetition trials (e.g., Smith, 1968). Repetition effects are readily observed even when the sequence of stimuli is selected randomly, indicating that the effect cannot be attributed to a tendency for the stimulus on trial $n - 1$ to predict the stimulus on trial n . Apparently, therefore, when the same stimulus is repeated, some aspect or aspects of the processing between stimulus and response proceeds more quickly. When a stimulus is repeated in a speeded-choice task, the stimulus, the response, and the stimulus-response (S-R) mapping from the previous trial are all repeated. Thus, a priori, one might suspect repetition of having effects anywhere from early sensory processing all the way to execution of the motor response. Several studies on the nature of this speedup were reported in the 1960s. The focus of these early studies was on the question of whether the effect occurs at the level of perception or response. (As will emerge shortly, these two alternatives do not exhaust the possibilities.)

Several investigators attempted to distinguish a response-locus hypothesis from a perception-locus hypothesis by using tasks in which several stimuli were mapped onto each of several responses. In this way, trials on which both stimulus and response were repeated (same-stimulus trials) could be

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compared with trials on which the stimulus was different but the response was the same (henceforth, same-response trials). Obviously, both can be compared with different trials on which neither response nor stimulus is repeated. In the early work, it was generally assumed that if same-response trials showed a benefit, then the effect could be located at the level of response execution. Another assumption generally made was that if the effect turned out to be specific to the stimulus (i.e., if same-response trials did not show a benefit), then the effect was perceptual. The latter inference may be misleading, because the effect might be specific to the stimulus even if it involved a speedup of postperceptual processes that selected rather than executed the response. To use one metaphor that will figure in the following discussion, if repetition strengthened a link between a stimulus representation and an abstract representation of the response, then other stimuli would not share in the benefit, even though the facilitation would precede the organization and execution of the motor response.

The early studies using this logic did not lead to a consensus. Bertelson (1965) had subjects perform a choice reaction-time task in which two even digits were mapped onto one response and two odd digits were mapped onto the other. He found that same-response trials were substantially faster than different trials, and only a little slower than same-stimulus trials. Rabbitt (1968) performed an experiment with digit stimuli. Every digit mapped onto the left key was numerically lower than every digit mapped onto the right key. He found a relatively small benefit for same-response trials compared with different trials; the same-stimulus trials were much faster than either. Smith (1968) examined repetition effects in a task requiring subjects to make one response to a red digit 1 or a green digit 2, and another response to a green 1 or a red 2. She found that the same-response trials were actually significantly slower than the different trials, whereas the same-stimulus trials were faster than either. Thus, previous findings conflict on the question of whether or not same-response trials receive any benefit or not. A possible reconciliation is discussed shortly.

Other investigators attempted to determine the locus of the repetition effect in speeded-choice tasks by examining the pattern of interaction between repetition and other variables following Sternberg's additive-factors method (Sternberg, 1969). Bertelson (1963) and Kornblum (1969) both found that repetition interacted with S-R compatibility. Specifically, the effect of S-R compatibility was smaller on repeated trials. S-R compatibility is generally presumed to affect the duration of response selection (here to be distinguished from response execution). More recently, several investigators found that repetition also interacted with the number of alternative response choices (Biederman & Stacy, 1974; Kornblum, 1975). In his early development of the additive-factors method, Sternberg (1969) found evidence that number of alternative response choices affects the duration of both response selection and perceptual processes. Together, then, the two results involving repetition seem to indicate that repetition definitely affects the duration of response selection and might possibly affect perceptual processing as well. Hansen and Well (1984) found, however, that repetition does not interact with a manipulation of visual stimulus quality. In view of the previous

results, this finding suggests that repetition does not affect the duration of perceptual processing. By elimination, then, the additive-factors studies together favor a response-selection locus for the effect.

This brief review suggests several points. Investigations using the additive-factors method have produced a relatively coherent picture, suggesting that repetition effects originate at the stage of response selection, which is speeded up when the same stimulus is repeated on two consecutive trials. Studies involving many-to-one mappings, on the other hand, have not produced any general agreement about whether repetition of the response without repetition of the stimulus is sufficient to produce facilitation. The goal of this article is to examine all these questions more systematically than previous research has allowed. Before turning to the experiments, however, some general issues and hypotheses are briefly discussed.

Possible Loci of the Repetition Effect

As noted previously here, there are in fact a substantial number of possible loci for the repetition effect. In the accompanying article (Pashler & Baylis, 1991), we delineated seven possible hypotheses concerning the locus of practice effects in speeded-choice tasks. A similar set of possibilities exists for the locus of repetition effects. In the case of repetition effects, we assume a transient speedup of processing along particular pathways that were used on the previous trial. By pathway, we refer to the processing at a given stage that takes the same input and produces the same output. Thus, on same-stimulus trials, response times are faster whenever the relevant pathway is reused. We briefly review a number of possibilities that were also considered as accounts of practice effect. Each of these received more extensive discussion in the earlier article. Figure 1 presents these possibilities applied to the repetition effect in a task where subjects press the left response key in response to any stimulus that is a letter.

First, the effect might originate in a speedup of perceptual processing, causing the pathway from the earliest visual representations to the identity of the character to operate more quickly (the perceptual speedup hypothesis). If this account were correct, then speedup on same-stimulus trials would probably occur only when the stimulus followed the same perceptual pathway (i.e., when it was physically identical). The second possibility—the categorization speedup hypothesis—would claim that the effect is due to quicker categorization of characters as, for example, letters or digits. This account pertains only to mappings where the stimuli assigned to a given response belong to a preexisting category (henceforth, categorizable mappings).

Several further possibilities for the locus of repetition effects involve the stage of response selection. According to the highest link hypothesis, the pathway from the category to the response might be transiently strengthened, thus speeding up the next response if that pathway was reused. By contrast, the shortcut hypothesis proposes the transient facilitation of a direct link between the individual character identity and the response category regardless of whether the stimuli assigned to that response could be grouped into categories. Thus, it would explain repetition effects by supposing that trials that

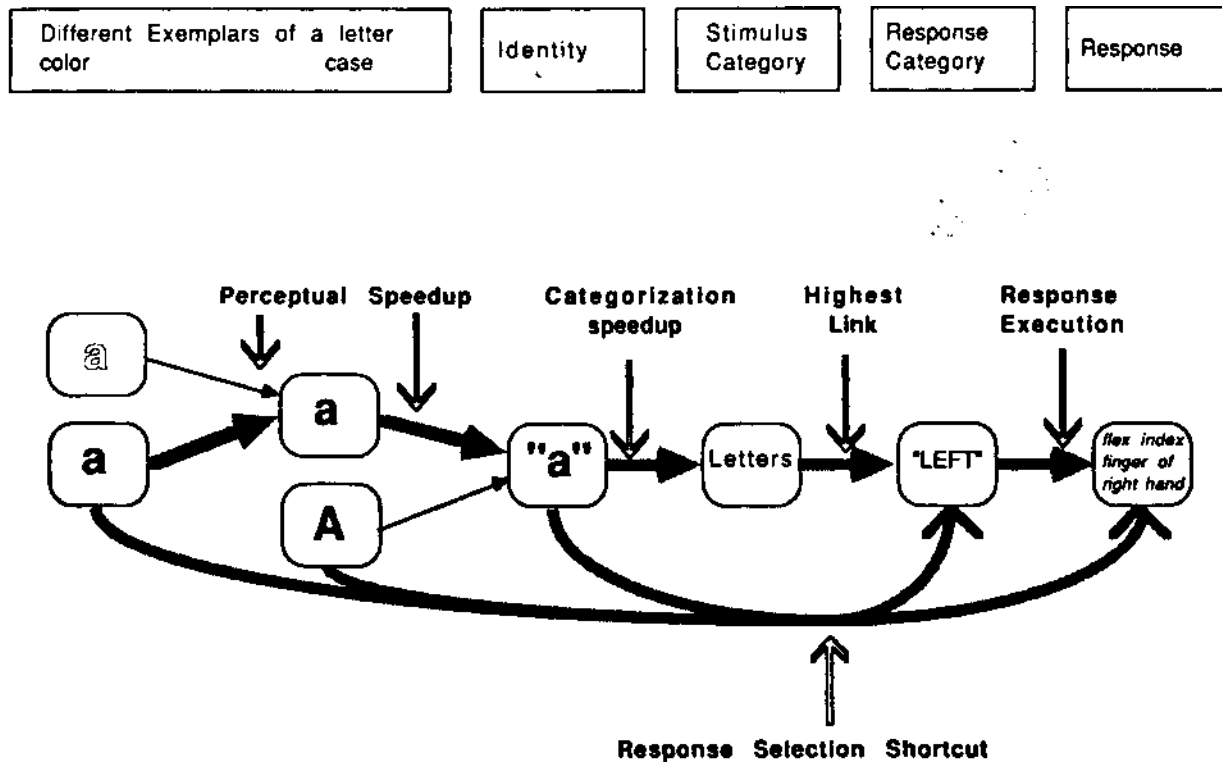


Figure 1. Possible loci for repetition effects in a task where the subject makes a left key response to any letter (irrespective of which letter, what case, or what color).

could use this shortcut would be facilitated. Bertelson (1963) proposed one version of a shortcut hypothesis according to which subjects may have a strategy of first comparing the new stimulus with a trace of the preceding one and, if there is a match, repeating the response without having to engage in the ordinary selection process.

Finally, the response execution speedup hypothesis proposes that repetition facilitates the execution of the response itself. Thus, it predicts that any trial in which the response is repeated will be facilitated.

In the previous article, we considered and rejected the possibility that practice might facilitate the pathways relevant to the entire mapping presented in the instructions, not just the pathways actually used during training. Plainly, such an effect could not produce a difference in the speed of responses to same-stimulus trials and different trials, so it is not considered further as a possible account of repetition effects.

Same-Response Trials—Why the Conflict?

Given the possible loci for the repetition effect just enumerated, we are in a position to consider how the empirical dispute noted earlier—concerning same-response trials—might be resolved. An examination of the experiments on each side of the issue suggests that the highest link hypothesis could reconcile these results. In the cases where there was a speedup of same-response trials, the different items mapped onto a given response seem like they probably belonged to

common conceptual categories with which the subjects were familiar. In Bertelson's (1965) work, odd and even digits were mapped onto different categories (although this was not mentioned to the subject). In Rabbitt's experiment, the fact that the digits mapped to one response were numerically higher than those mapped to the other response raises the possibility that the subjects may have adopted two categories such as "high digits" and "low digits." Both of these studies showed faster responses on same-response trials. In Smith's experiment, on the other hand, no conceptual category seems to have existed, and same-response trials were actually slower than different trials.

If the primary locus of the repetition effects were in a transient strengthening of links between category and response (highest link hypothesis), then exactly this pattern of effect would be predicted. That is, one would observe facilitation for the same-response condition compared with the different condition, just in case a category node existed that encompassed the different stimuli mapped onto the same response. The following experiments address this possible reconciliation of the disagreements concerning repetition effects noted.

The Relation Between Repetition and Practice Effects

As this brief review indicates, a number of investigators have attempted to determine the source of repetition effects in speeded-choice tasks. This work led to empirical disagreements, and one possible explanation for these was just consid-

ered. Before beginning to test these explanations, we turn now to a broader question about repetition effects. Considered abstractly, repetition effects are basically learning effects that rapidly decline as the lag (number of intervening stimuli) from the initial occurrence increases. (One can tell that the effect must rapidly dissipate with increasing lags simply by considering the lag-one repetition effects themselves: If they did not dissipate, they would cumulate so that all trials would show an approximately equal benefit of repetition from all the earlier trials of the experiment. Given the size of the immediate repetition effect, this makes no sense.) However, the fact that the cause of the repetition effect rapidly dissipates is actually consistent with the possibility that it is identical to the cause of the practice effect (that emerges gradually over trials).

In previous research, practice and repetition effects have been addressed separately, and any possible connections between them have been neglected. On the one hand, they might be unrelated: Thus, any given trial might produce two distinct changes, one a transient effect that could speed up the subsequent trial were it a repetition, and the other a longer lasting change that gradually produces overall improvement in performance. Another possibility, though, is that repetition and practice effects might reflect exactly the same underlying experience-induced changes. Suppose, for instance, that when a stimulus is presented and responded to, a memory trace remains that will speed up the selection of the same response should the same stimulus be presented again. Assume further that this trace has a negatively accelerated decay function (i.e., it decays rapidly at first, then more and more slowly). Suppose also that it never completely decays away (i.e., it approaches a very small but nonzero asymptote). These assumptions could naturally account for both the repetition and practice effects. The comparison of same-stimulus and different trials (i.e., the repetition effect) would depend on the effect of the not-much-decayed trace originating from the previous trial. Over the course of repeated trials, the accumulation of multiple traces that have not quite decayed to zero would sum to yield the practice effect.

The idea that the practice effect might originate in the accumulation of multiple traces left over from previous individual trials was proposed by Logan (1988). However, Logan's account postulates no decay of these traces with time or lag. It also proposes a novel mechanism whereby these multiple traces could act together to produce the speedup caused by practice. Basically, each new trace spawns a memory-retrieval process (with a certain variability in its duration), and on each trial all of the previously spawned processes race with each other to be the first to retrieve the appropriate response on succeeding trials. This race model correctly predicts certain quantitative features of the practice function, involving the mean and variance of response times. However, a difficulty with this proposal is that because it assumes no decay of the traces with time or lag, it therefore predicts that the repetition effect will not be reduced with delay or lag either. Thus, it cannot account for the large observed difference between same-stimulus and different trials. It is not clear whether, if Logan's model were changed to include such decay, it could still make the same predictions as the existing formulation. It seems to us to be premature at this time to develop detailed

models such as Logan's if they are not in the appropriate class of models to start with. To answer this question, one goal of work reported here is to test the general hypothesis that repetition and learning effects can be attributed to the same source, by determining if they have the same locus of effect, and transfer under the same conditions.

Research Strategy

We begin with five experiments that examine the crucial and disputed question of repetition effects on same-response trials. Previous experiments differ on this question, as noted previously here. However, these early experiments mostly involved necessarily small amounts of data, included some rather quirky features, and differed one from another in a variety of ways. Thus, no systematic comparison is possible from previous data. In the first five experiments, we attempt to determine what variables may be determining whether same-response trials show a benefit. All of the first five experiments involve letters, digits, and nonalphanumeric symbols as stimuli, and three manual responses. There are several reasons for selecting three-choice tasks. Repetition effects are sometimes small and unpredictable with two-choice tasks (e.g., Hale, 1967). This is probably because subjects tend (irrationally) to anticipate alternations in two-choice tasks, which can undermine the repetition effects. In addition, three-choice tasks produce much larger effects than two-choice tasks (this is the interaction of repetition with number of alternatives noted previously here). The experiments reported next explicitly manipulate whether the stimuli mapped onto a given response belong to a common conceptual category to determine if this actually has the effects suggested previously. In addition, the experiments will make it possible to compare the task conditions under which trials show a repetition effect with those allowing transfer of practice effects (Pashler & Baylis, 1991). In this way, the possible relationships between practice and repetition effects can be examined. Before presenting the experiments individually, a description of the general methodology is provided to avoid redundancy.

General Method

Subjects

Undergraduates at the University of California, San Diego participated as subjects in the experiment in partial fulfillment of a course requirement or for payment.

Apparatus and Stimuli

The stimuli were presented on Princeton Graphics SR-12 monitors controlled by IBM PC microcomputers (equipped with Sigma Design Color-400 boards, providing a display resolution of 640 x 400 pixels), and responses were collected on the PC keyboards. The stimulus was a centrally located character. The mapping of stimuli onto responses was constant for all subjects throughout the experiment. The left response key was the "M" key, the middle response key was the "," key, and the right response key was the "." key. The mappings and instructions are described for each experiment individually, but Table 1 provides a reference to the S-R assignment used in each experiment.

Table 1
Stimuli Mapped Onto Each Response in Experiments 1-7

Experiment	Response					
	Left		Middle		Right	
1: Uncategorizable	4	P	2	V	8	K
2: Small categorizable	2	4	P	V	&	#
3: Large categorizable	2	7	P	V	&	#
	4	9	K	W	%	=
4: Case variation	G	g	A	a	Q	q
5: Color variation	G		A		Q	
6: Task alternation						
Manual	4	P	2	V	8	K
Vocal	4→	"4"	2→	"2"	8→	"8"
	P→	"P"	V→	"V"	K→	"K"
7: Hand alternation versus right hand only	4	P	2	V	8	K

Responses were made with the first three fingers of the right hand. The stimulus to be presented on each trial was chosen randomly without any constraint from the set of six possible stimuli. The characters measured about .6 cm width by .5 cm height, and were presented in yellow on a black background. Based on a typical viewing distance of 60 cm, the characters subtended a visual angle of .57 by .48 degrees.

Design

The experiment was divided into 20 blocks of 50 trials each. Except where noted, response-stimulus interval (RSI) was a within-subject, between-block factor and represented the interval (100 ms vs. 1,000 ms) from each keypress response to the onset of the stimulus for the next trial. Stimulus selection was completely randomized (individually for each subject) with replacement, so that the numbers of trials in each repetition condition varied. The expected proportion of stimulus repetition trials was 1/6; response but not stimulus repetitions, 1/6; and nonrepetition trials, 2/3. The first trial on each block was not counted in any condition. Each subject performed 10 blocks with 100-ms RSI, and 10 blocks with a 1,000-ms RSI. The RSI alternated from block to block, and half of the subjects started with a 100-ms RSI for their first block, whereas the other half of the subjects started with a 1,000-ms RSI.

Procedure

The subjects were given instructions in writing describing the task. The instructions stated that the response should be made as rapidly and accurately as possible. Before data collection, each subject worked through 100 practice trials, in two blocks of 50 trials each (one for each RSI). During the practice, the subjects had available a card with the assignment of stimuli to responses printed out in large letters in case they momentarily forgot the mapping. At the end of each block, the subject rested until he or she felt ready to resume. At this time, feedback was provided for each of the preceding blocks consisting of mean correct response times and number of errors.

Data Analysis

For analysis of mean reaction times, response latencies under 200 ms or over 2,000 ms were discarded as deviant.

Experiment 1: Repetition With an Uncategorizable Mapping

The first experiment examined intertrial repetition effects with a task in which two stimuli were assigned to each of three response keys. The stimuli were selected to minimize any possibility that the different stimuli mapped onto a given response could be grouped into already familiar conceptual categories. The interval from response to the appearance of the next stimulus was either 100 ms or 1,000 ms. In this way, it was possible to look for evidence of rapid decay of any repetition effects that might be observed. In addition, a substantial amount of data was collected so that response-time distributions could be meaningfully examined.

Method

Sixteen subjects participated. The characters "4" and "P" were mapped onto the left response key, "2" and "V" were mapped onto the middle response key, and "8" and "K" were mapped onto the right response key.

Results and Discussion

Mean reaction times. Figure 2 presents the mean correct response times as a function of RSI and transition type (i.e., the relationship of the preceding stimulus to the response in question). As Figure 2 shows, subjects were faster with the longer RSI (623 ms vs. 570 ms), $F(1, 15) = 53.9, p < .001, MS_e = 1,278$. Subjects were faster for the same-stimulus trials (486 ms) than for same-response trials (where the stimulus was different; 661 ms) or different trials (642 ms), $F(2, 30) = 117.4, p < .001, MS_e = 2,514$. Figure 2 shows that the effect of RSI was smaller for stimulus repetitions than for the other two conditions, reflecting the significant interaction between RSI and repetition condition, $F(2, 30) = 5.5, p < .01, MS_e = 699$.

Error rates. With the short (100 ms) RSI, the mean proportions of errors were .006, .087, and .033 for same-stimulus, same-response, and different transitions, respectively. The corresponding figures for the long (1,000 ms) RSI were .034, .082, and .058, respectively. Overall, there were slightly more errors for the long RSI (.058) than for the short RSI (.042),

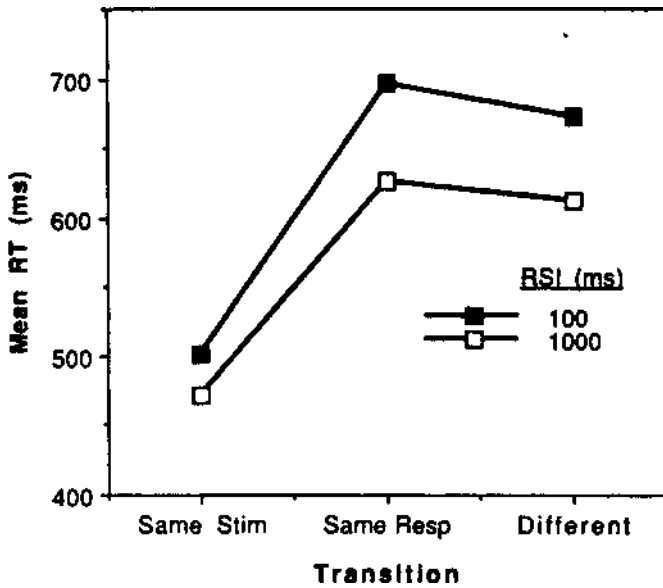


Figure 2. Mean reaction times (RTs) in Experiment 1 as a function of (immediate) transition type. (Stim = stimulus; Resp = response; RSI = response-stimulus interval.)

$F(1, 15) = 5.4, p < .05, MS_e = 0.0011$. The effect of repetition condition on error rates was highly significant, $F(2, 30) = 39.4, p < .001, MS_e = 0.0009$, and the interaction of RSI and repetition condition was also significant, $F(2, 30) = 4.5, p < .05, MS_e = 0.0006$.

The results indicate that there was a large beneficial effect of repeating the same stimulus, as expected. In addition, performance was actually somewhat worse when a trial was preceded by a trial on which the response, but not the stimulus, was the same. This effect was also observed by Smith (1968), who used a mapping in which there was no obvious conceptual grouping of the stimuli assigned to given responses. The poorer performance on same-response trials is most pronounced in errors, but mean response times tend in the same direction.

Lag effects. The data were also broken down according to the relationship of the current trial to trials preceding it at lags of -2 and -3. Figure 3 shows mean response times according to relationship and lag plotted on the same scale. Thus, the filled triangle at lag -3 on the line labeled "Different" represents the mean of all response times for any trial n such that on trial $n - 3$ a stimulus was presented that called for a different response regardless of what events intervened. As expected, the repetition effects are attenuated with increasing lag still being quite evident at lag -2 but nearly disappearing by lag -3. The attenuation with lag cannot be entirely or even primarily due to the passage of time. In the 100-ms RSI condition, lag -2 repetitions reflect responses to stimuli that previously appeared approximately 850 ms earlier than the current stimulus. In the 1000-ms RSI conditions, lag -1 repetitions reflect responses to stimuli that previously appeared 1,000 ms earlier. Nonetheless, the lag -2 repetition effect in the 100-ms RSI condition is much smaller than the lag -1 effect in the 1,000-ms RSI condition.

Experiment 2: Repetition With a Categorizable Mapping

The previous experiment used an assignment of stimuli to responses that was designed to avoid having the stimuli mapped to a given response share a preestablished common category. The present experiment was identical except that here the mapping provided a clear and salient conceptual grouping of the stimuli assigned to each response. Two digits were mapped to the left response key, two letters to the middle

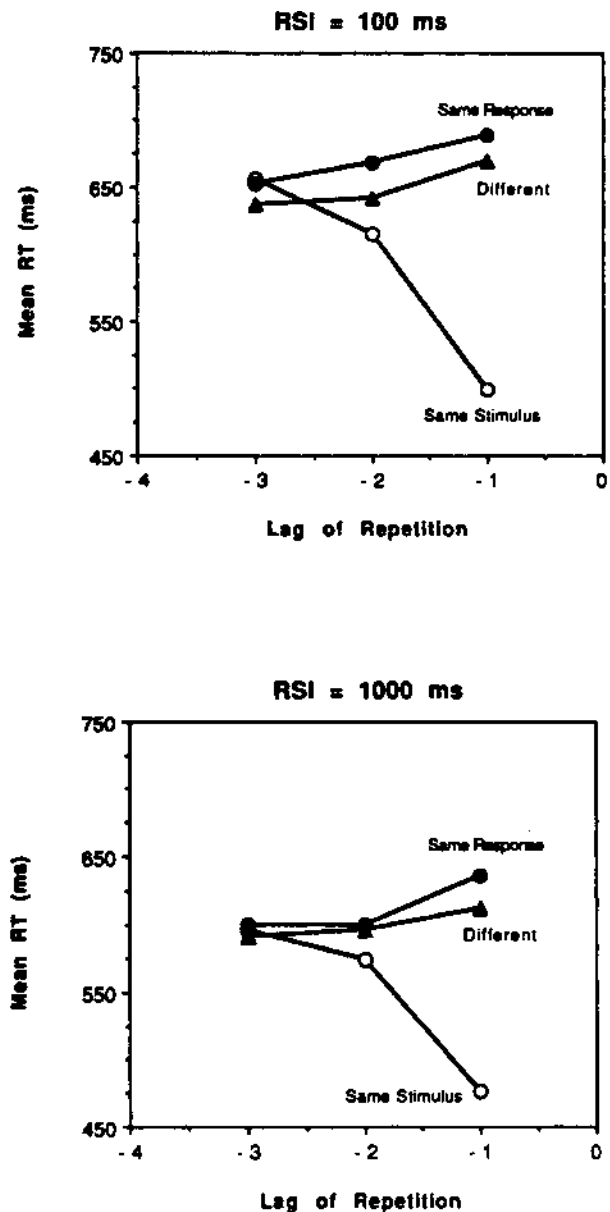


Figure 3. Extended lag effects in Experiment 1. (Mean response times [RTs] according to relationship of current trial n to trial n minus lag of repetition. Top panel: 100-ms response-stimulus interval [RSI]; bottom panel: 1,000-ms response stimulus interval.)

response key, and two nonalphanumeric symbols ("&" and "#") to the right response key.

Method

Twelve undergraduates at the University of California, San Diego participated as subjects in the experiment in partial fulfillment of a course requirement. The characters "2" and "4" were mapped onto the left response key, "P" and "V" were mapped onto the middle response key, and "&" and "#" were mapped onto the right response key.

Results and Discussion

Mean reaction times. Figure 4 presents the mean correct response times as a function of RSI and transition type (i.e., the relationship of the preceding stimulus to the response in question). As Figure 4 shows, subjects were faster with the longer RSI (589 ms vs. 548 ms), $F(1, 11) = 29.3, p < .001, MS_e = 1,013$. Subjects were faster for the same-stimulus trials (494 ms) than for same-response (different stimulus) trials (593 ms) or different-response trials (619 ms), $F(2,22) = 57.5, p < .001, MS_e = 1,810$. The interaction between RSI and repetition condition was not significant, $F < 1$.

Error rates. With the short (100 ms) RSI, the mean proportions of errors were .008, .049, and .028 for same-stimulus, same-response, and different transitions, respectively. The corresponding figures for the long (1,000 ms) RSI were .020, .058, and .050, respectively. Overall, there were slightly more errors for the long RSI (.043) than for the short RSI (.028), $F(1, 11) = 8.5, p < .02, MS_e = 0.0004$. The effect of repetition condition on error rates was highly significant, $F(2, 22) = 19.4, p < .001, MS_e = 0.0005$. The interaction of RSI and repetition conditions was not significant, $F < 1$.

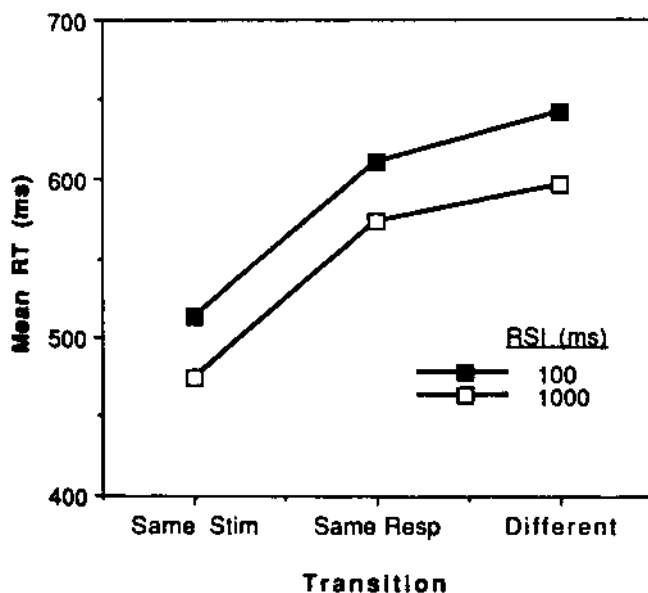


Figure 4. Mean response times (RTs) in Experiment 2 as a function of (immediate) transition type. (Stim = stimulus; Resp = response; RSI = response-stimulus interval.)

As in the first experiment, there was a very substantial benefit for the same-stimulus trials compared with different trials, $t(11) = 8.7, p < .001$. In this experiment, however, the same-response trials were 27 ms faster than the different trials. This effect was marginally significant, $t(11) = 2.97, p < .05$.

The results show that same-response trials were facilitated to only a small fraction of the degree to which same-stimulus trials were facilitated. This is despite the fact that the different stimuli mapped onto the same response also belonged to a conceptual category. If the repetition effect stems from the short-term activation of the links between the category and the response, then the same-response trials in this experiment should have shown a dramatic benefit. By contrast, the preceding report (Pashler & Baylis, 1991) found that the transfer of the practice effect was excellent to new items in the same categories. Evidently, then, the repetition effect reflects a different kind of learning effect from that underlying the practice effect; this question is discussed further later.

Experiment 3: Repetition With a Larger Categorizable Mapping

One might propose that the failure to find a major benefit for same-response trials with a categorical mapping—observed in the previous experiment—is simply due to the small size of the mapping used there. Perhaps subjects do not rehearse and use the categorizable mapping in favor of rehearsing the subset of characters presented. It is conceivable that the links strengthened by the repetition effect depend on the way the subjects represent the mapping to themselves. In the present experiment, there were four stimuli assigned to each response, drawn from the same conceptual categories as those used in the other experiments. In this situation, it seems very unlikely that the subjects would or could remember the whole collection of stimuli individually.

Method

Fourteen students participated as subjects. There were four characters mapped onto each of the response keys. The digits "2," "4," "7," and "9" were mapped onto the left response key, the letters "P," "V," "K," and "W" were mapped onto the middle response key, and the symbols "&," "#," "%," and "=" were mapped onto the right response key.

Results and Discussion

Mean reaction times. Figure 5 presents the mean correct response times as a function of RSI and transition type (i.e., the relationship of the preceding stimulus to the response in question). As Figure 5 shows, subjects were faster with the longer RSI (543 ms vs. 586 ms), $F(1, 13) = 22.6, p < .001, MS_e = 1,718$. Subjects were faster for the same-stimulus trials (490 ms) than for same-response (different stimulus) trials (576 ms) or different-response trials (628 ms), $F(2, 26) = 66.4, p < .001, MS_e = 2,035$. The interaction between RSI and repetition condition was not significant, $F(2, 30) = 1.5, MS_e = 480$.

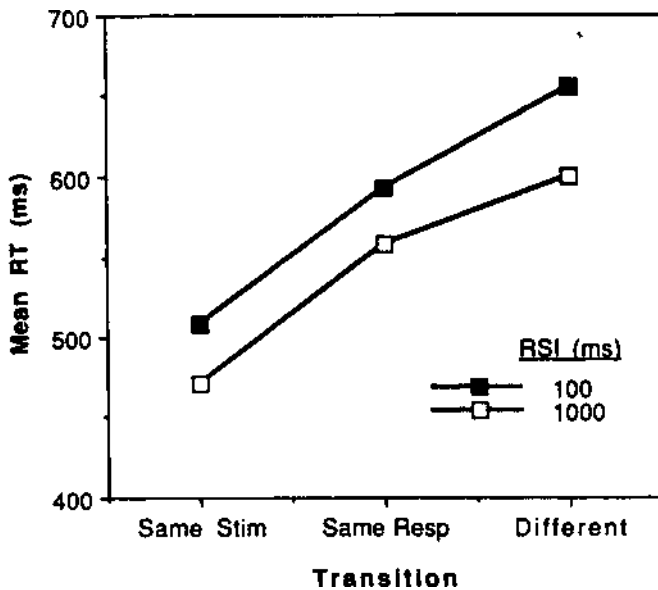


Figure 5. Mean response times (RTs) in Experiment 3 as a function of (immediate) transition type. (Stim = stimulus; Resp = response; RSI = response-stimulus interval.)

Figure 6 shows the mean response times for repetition lags of -1, -2, and -3, by type of repetition, as described in Experiment 1. The advantage for same stimulus remains at lag -2, but the difference between same-response trials and different trials virtually disappears at both the short and long RSI. As in the previous experiment, note that the lag -2 repetition effect at the short RSI is reduced to being much smaller than the lag -1 repetition effect at the long RSI, indicating that an intervening trial reduces repetition effects much more dramatically than the sheer passage of time that it occupies.

As in the first experiment, there was a very substantial benefit (138 ms) for the same-stimulus trials, $t(13) = 9.7, p < .001$. In this experiment, however, the same-response trials were 52 ms faster than the different trials. This response repetition effect was significant, $t(13) = 4.5, p < .001$. These results indicate that when items assigned to a given response are drawn from a common conceptual category, and the items assigned to each response are numerous enough, there is a substantial benefit. However, this saving is still less than half the size of the total repetition effect obtained for same-stimulus trials. In short, the results converge with those of Experiment 2 to argue against an identical basis for the practice and repetition effects.

Error rates. With the short (100 ms) RSI, the mean proportions of errors were .008, .036, and .052 for same-stimulus, same-response, and different transitions, respectively. The corresponding figures for the long (1,000 ms) RSI were .018, .053, and .086, respectively. Overall, there were slightly more errors for the long RSI (.053) than for the short RSI (.032); this was significant, $F(1, 13) = 8.1, p < .02, MS_e = 0.0011$. The effect of repetition condition on error rates was highly significant, $F(2, 26) = 28.3, p < .001, MS_e = 0.0008$. The interaction of RSI and repetition condition was almost but

not quite significant, $F(2, 26) = 3.2, .05 < p < .10, MS_e = 0.0003$.

Experiment 4: Case and Repetition

The preceding experiments have observed that the repetition effect is quite stimulus specific (and in particular, that it appears to be more stimulus specific than the practice effect). The present study and the following one were designed to test the limits of how stimulus specific the effect is. In Experiment 4, the mapping was from letters to responses, with task-

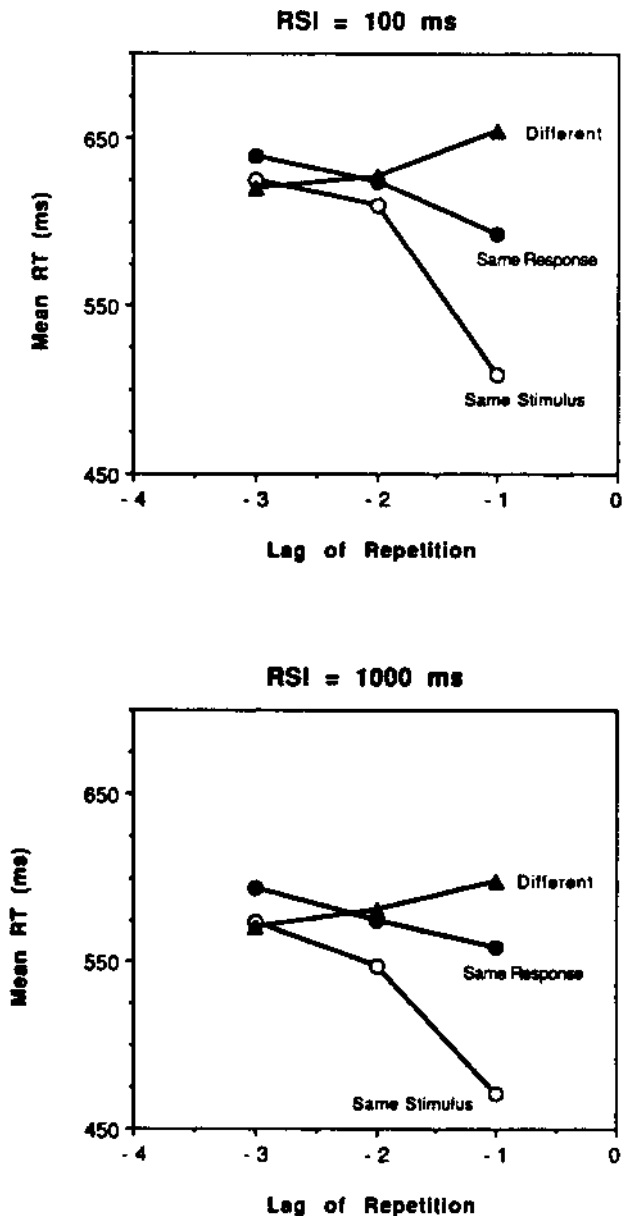


Figure 6. Extended lag effects in Experiment 3. (Mean response times [RTs] according to relationship of current trial n to trial n minus lag of repetition. Top panel: 100-ms response-stimulus interval [RSI]; bottom panel: 1,000-ms response-stimulus interval.)

irrelevant variation in the case of the letters. Will a beneficial repetition effect be observed on same-response trials (i.e., on trials where the letter is repeated, but in a different case)?

Method

Eighteen subjects participated. There was only one letter mapped onto each response key (which could appear in either uppercase or lowercase). The letter "G" (or "g") was mapped onto the left response key, the letter "A" (or "a") was mapped onto the middle response key, and the letter "Q" (or "q") was mapped onto the right response key. These three letters were selected because the uppercase and lowercase versions of these letters do not particularly resemble each other.

Results and Discussion

Mean reaction times. Figure 7 presents the mean correct response times as a function of RSI and transition type (i.e., the relationship of the preceding stimulus to the response in question). As Figure 7 shows, subjects were faster with the longer RSI (588 ms vs. 551 ms), $F(1, 17) = 32.8$, $p < .001$, $MS_e = 1,113$. Subjects were faster for the same-stimulus trials (503 ms) than for same-response (different stimulus) trials (589 ms) or different-response trials (617 ms), $F(2, 34) = 116.6$, $p < .001$, $MS_e = 1,090$. The interaction between RSI and repetition condition was significant, $F(2, 30) = 9.3$, $p < .001$, $MS_e = 566$. This reflects the fact that the effect of RSI is minimal for same-stimulus trials.

As in the first experiment, there was a very substantial benefit (114 ms) for the same-stimulus trials compared with the different trials, $t(17) = 14.0$, $p < .001$. In this experiment, the same-response trials are a modest 27 ms faster than the different trials. This effect was significant, $t(17) = 3.3$, $p < .01$.

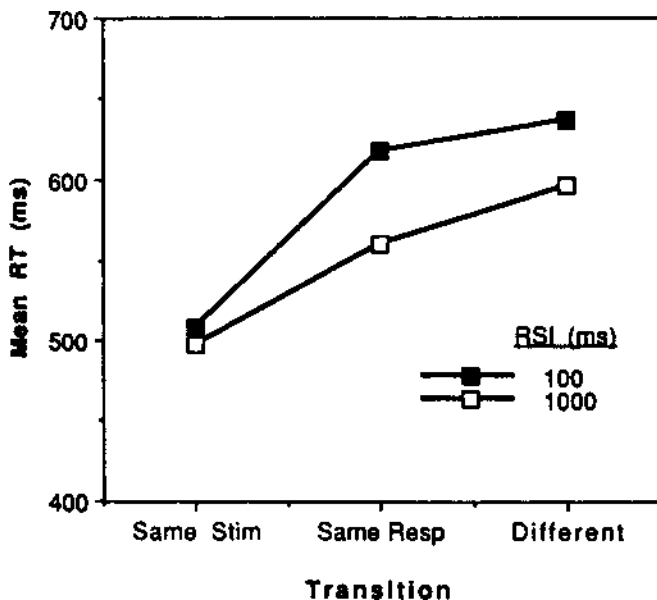


Figure 7. Mean response times (RTs) in Experiment 4 as a function of (immediate) transition type. (RSI = response-stimulus interval.)

.01. Despite the fact that these characters are different tokens of very well-learned types, the repetition effect was mostly stimulus specific.

Error rates. With the short (100 ms) RSI, the mean proportions of errors were .007, .051, and .039 for same-stimulus, same-response, and different transitions, respectively. The corresponding figures for the long (1,000 ms) RSI were .028, .048, and .062, respectively. As in the previous experiments, there were slightly more errors for the long RSI (.046) than for the short RSI (.033); this was not quite significant, $F(1, 17) = 4.0$, $.05 < p < .10$, $MS_e = 0.0012$. The effect of repetition condition on error rates was highly significant, $F(2, 34) = 15.1$, $p < .001$, $MS_e = 0.0008$. The interaction of RSI and repetition condition was almost but not quite significant, $F(2, 34) = 3.1$, $.05 < p < .10$, $MS_e = 0.0006$.

Experiment 5: Color and Repetition

The previous experiment showed that the same-response trials show only a very modest repetition effect despite the fact that these trials represent repetition of the same character with only a change from uppercase to lowercase or vice versa. Experiment 5 attempts to identify whether an even more superficial variation will succeed in producing a benefit for these same-response trials. Here we varied a dimension that is not only irrelevant to the task (as was letter case in the preceding experiment) but also perceptually separable from the task-relevant dimension, namely color (see, e.g., Garner, 1974).

Method

Twelve subjects participated. The stimuli were presented as in the first experiment, except that there was only a single letter mapped onto each response key. As in Experiment 4, the letter "G" was mapped onto the left response key, the letter "A" was mapped onto the middle response key, and the letter "Q" was mapped onto the right response key. In contrast to Experiment 4, the letters were always presented in uppercase, but half of the time they were presented in green and the other half they were presented in red. The stimulus selection worked exactly as in the previous experiments, only here a green and a red instance of the same letters counted as a different stimulus.

Results and Discussion

Mean reaction times. Figure 8 presents the mean correct response times as a function of RSI and transition type (i.e., the relationship of the preceding stimulus to the response in question). As Figure 8 shows, subjects were faster with the longer RSI (537 ms vs. 512 ms); this difference was not quite significant, $F(1, 11) = 3.8$, $.05 < p < .10$, $MS_e = 3005$. Subjects were faster for the same-stimulus trials (481 ms) than for same-response (different stimulus) trials (504 ms) or different-response trials (589 ms), $F(2, 22) = 52.8$, $p < .001$, $MS_e = 52.8$. The interaction between RSI and repetition condition was significant, $F(2, 22) = 6.3$, $p < .01$, $MS_e = 398$. This reflects the fact that the effect of RSI was reduced for both same-stimulus and same-response trials.

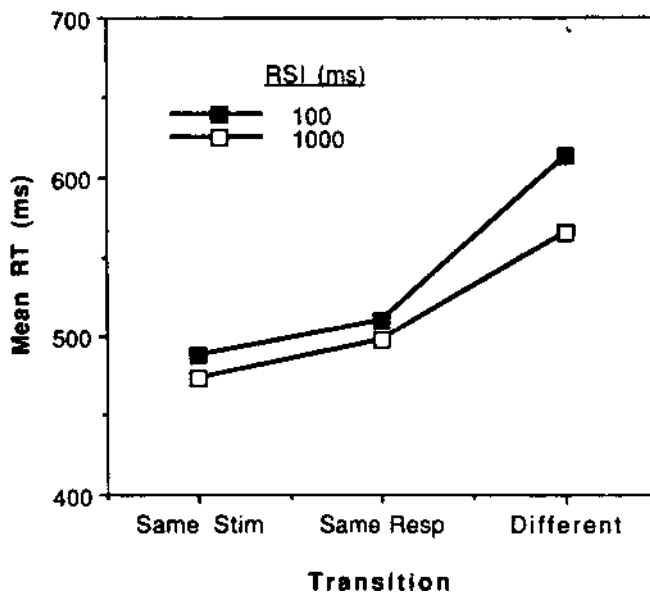


Figure 8. Mean response times (RTs) in Experiment 5 as a function of (immediate) transition type. (RSI = response-stimulus interval: Stim = stimulus; Resp = response.)

As in the earlier experiments, there was a very substantial benefit for the same-stimulus trials compared with the different trials, $t(17) = 14.0$, $p < .001$. In this experiment, however, the same-response trials were 85 ms faster than the different trials, $t(17) = 3.3$, $p < .01$. Apparently, then, when the difference between stimuli assigned to a given response is superficial enough, the same-response trials do show nearly the full repetition effect.

Error rates. With the short (100 ms) RSI, the mean proportions of errors were .007, .015, and .038 for same-stimulus, same-response, and different transitions, respectively. The corresponding figures for the long (1,000 ms) RSI were .024, .031, and .048, respectively. As in the previous experiments, there were slightly more errors for the long RSI (.035) than for the short RSI (.020), $F(1, 11) = 10.9$, $p < .01$, $MS_e = 0.0003$. The effect of repetition condition on error rates was highly significant, $F(2, 22) = 15.3$, $p < .001$, $MS_e = 0.0003$. The interaction of RSI and repetition condition was not significant, $F(2, 22) = 0.3$, $p > .50$, $MS_e = 0.0003$.

Discussion of Experiments 1 to 5

The results of the five experiments reported here indicate that the repetition effect is remarkably stimulus specific. When two stimuli that are mapped onto the same response are presented in succession, there is relatively little speedup for the second response. Increasing the degree to which the stimuli share membership in a common conceptual category increases this speedup, but it is only when the two stimuli differ only in a completely incidental attribute (color) that we observe virtually complete transfer.

This result contrasts with the findings in the previous article (Pashler & Baylis, 1991) concerning the practice effect in the

same kinds of tasks. There, practice with one mapping shows excellent transfer to new stimuli that are mapped onto the same response, so long as the different stimuli associated with that response all belong to a common conceptual category. This result speaks against the suggestion, raised earlier here, that the repetition effect might involve strengthening of links between the most abstract categories subsuming the stimuli mapped to a given response and that response (see Figure 1). In turn, this argues against the idea that the practice effect results entirely from the accumulation of the same traces as those responsible for the repetition effect.

One interesting finding that emerged in all five of the experiments reported here concerns the effects of the interval between one response and the presentation of the next stimulus (RSI). In general, increasing the RSI from 100 to 1,000 ms produced a very small reduction in the size of the repetition effect. The small size of the RSI effects has been noted previously (Ells & Gotts, 1977). (The examination of lags showed that an intervening trial contributes far more than the passage of a little time toward reducing these effects.) This fits with the idea that a very slow decay of the repetition effect is under way. More unexpected, however, were the effects of RSI on speed and accuracy. Reducing the RSI retarded responses significantly in all the experiments. This is not unexpected, because the reduction in RSI inevitably reduces the subjects' preparedness for the subsequent task. What is interesting, however, is the fact that the shorter RSI was also accompanied by a reduction in the error rates. This effect occurred in all five experiments, although it was only significant in some of them. It seems that RSI reduction is producing a (presumably involuntary) change in where the subjects position themselves on their speed-accuracy trade-off functions. This suggests that the reduction in preparedness is delaying the point at which responses are selected or initiated, without delaying much the buildup of the information on which these responses are based.

The results of the experiments reported thus far bear on several different possibilities for the locus of the repetition effect. First, the repeated finding that the same-response (different stimulus) trials are often at least as slow as different trials speaks directly against the possibility that the effect involves a speedup of response execution. However, the results are consistent with two of the possibilities that were raised initially. The first possibility is that the effect is perceptual. The stimulus specificity of these effects would be expected if the speedup originates in the identification of the stimuli. This would be consistent with the fact that the same-response trials show the full repetition effects only when the different stimuli mapped onto a given response differ only in as superficial an attribute as color (Experiment 5).

Various evidence reviewed initially here, however, seemed to argue against a perceptual locus for the repetition effect. Experiments using the additive-factors method found interactions between repetition and variables affecting the duration of response selection, suggesting that the locus of the effect must be in that stage. How could a response-selection locus for the effect be reconciled with its high degree of stimulus specificity? One possibility is labeled response-selection shortcut in Figure 1. On this conception, the repetition effect is

not due to a reinforcement of the pathways between categorical nodes and the response, but instead represents shortcuts to response selection (i.e., pathways whereby lower level stimulus codes can directly activate the appropriate responses). This account would be particularly interesting in view of the conclusion of the preceding article, that the greater proportion of the practice effects in tasks like these do not originate in shortcuts of this kind. The next experiment attempted to empirically distinguish the perceptual locus hypothesis from the response-selection shortcut hypothesis. To do this, we ask whether repetition of the same stimulus on two consecutive trials, but with different responses being selected in each case, produces the repetition benefit.

Experiment 6: Repetition and Response Modality

Experiment 6 investigates the locus of the repetition effect by examining what happens when the same stimulus is presented on successive trials, but with different responses to be selected, because of a change in the mapping from trial to trial. If the repetition effect operates to facilitate response selection (as suggested by the response-selection shortcut model), a change in the mapping should plainly abolish the effect. If the effect is perceptual, on the other hand, the effect should persist. Ellis and Gotts (1977) reported an experiment with some similarities to this. In their study, subjects performed a Sternberg memory-scanning task of a go-no-go variety, responding whenever the probe belonged to the memory set. The motor response depended on the spatial position of the probe, allowing Ellis and Gotts to study stimulus repetitions without response repetition (by presenting the same probe twice in a row, but in different positions). They found a sizable stimulus-repetition effect. Their task was substantially more complicated than the speeded-choice tasks examined here, however, so the effect of repetition of the stimulus alone in their design could well reflect a speedup of stages of processing absent in our tasks (the obvious candidate being memory scanning itself).

Single characters were presented on each trial, and subjects responded either with a manual choice response or by naming the character aloud. In some blocks, all trials required manual choice responses, whereas in other blocks the task alternated between manual choice and vocal naming. The basic question was simply whether the manual responses would be facilitated by a repetition of the stimulus from the previous trial, when the previous trial involved a vocal, rather than a manual, response.

Method

Fourteen subjects participated. The stimuli were presented as in Experiment 1, and for manual responses, the mapping was the same as that one. On half of the blocks of trials, subjects were instructed to make the appropriate manual response to each stimulus on every trial. On the other blocks of trials, subjects were instructed to name the stimulus on the odd-numbered trials and to make a button-push response on the even-numbered trials. In all blocks of trials, the Position of the stimulus alternated from trial to trial: On the odd-numbered trials the stimulus was slightly above fixation, and on even-

numbered trials it was slightly below the fixation. Thus, on the mixed vocal/manual blocks, subjects did not have to remember whether the trial number was odd or even, they merely named all those characters presented above fixation and made a manual choice response to characters below fixation. The same alternating presentation positions were used in the pure manual blocks as well, so that positional change was not confounded with response-modality change. Pure manual blocks alternated with vocal/manual blocks. Half of the subjects began with a pure manual block, and the remainder began with a vocal/manual block. Vocal naming responses were not recorded, but subjects were monitored to ensure that they made prompt vocal responses. On the naming trials, the duration that the stimulus remained present was set to 750 ms on the first block, and thereafter it was yoked to the mean response time in the preceding block, which involved purely manual responding. In this way, the average exposure duration for the stimulus and the interval between stimulus presentations were kept approximately constant for the two conditions (although the small effects of RSI in the earlier experiments do not suggest that this is particularly critical). The time from stimulus offset to the onset of the next stimulus was 1,000 ms.

Results and Discussion

Mean reaction times. The data from one subject were lost. Figure 9 presents the mean correct manual response times as a function of transition type (i.e., the relationship of the preceding stimulus to the response in question) and block type (manual-manual blocks vs. vocal-manual blocks). As Figure 9 shows, subjects were slightly faster for manual responses that followed vocal responses (567 ms vs. 586 ms); this difference was not significant, $F(1, 12) = 3.0, p > .10, MS_e = 2303$. The graph shows clearly that the repetition facilitation is abolished in the vocal-manual condition. The interaction of block type with condition was significant, $F(2, 24) = 24.1, p < .001, MS_e = 1221$. For the vocal-manual condition, the comparison of same-stimulus and different

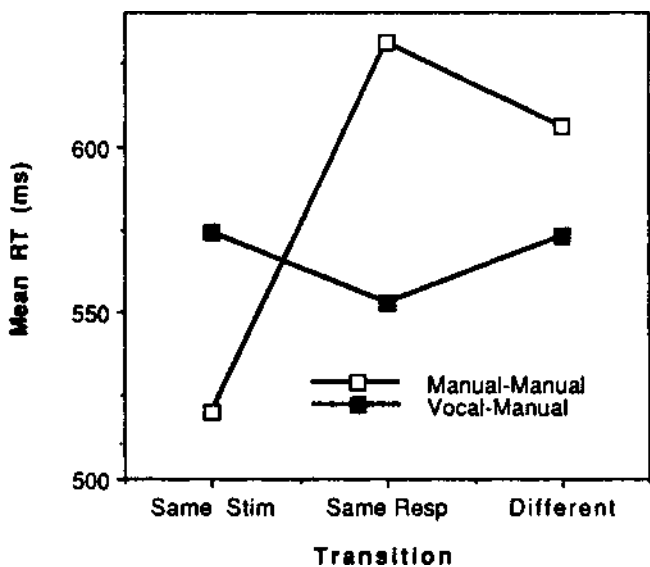


Figure 9. Mean response times (RTs) in Experiment 6 as a function of (immediate) transition type. (Stim = stimulus; Resp = response.)

trials was nonsignificant, $F(1, 12) = 0.02$, $p > .85$, $MS_e = 736$.

An analysis of the lag -2 repetition effects showed sizable effects in both conditions. For the manual-manual condition, the mean response times for same-stimulus, same-response, and different conditions are 570 ms, 601 ms, and 595 ms, respectively. For the vocal-manual condition (manual responses only), they are 536 ms, 575 ms, and 577 ms, respectively. (Note that these reflect the relationship to the preceding manual response, given the alternating response procedure.) The effect of repetition condition at lag -2 was significant, $F(2, 24) = 16.3$, $p < .001$, $MS_e = 610$, but the interaction of repetition with task condition was nonsignificant, $F < 1$, $MS_e = 633$.

Error rates. In the manual-manual condition, the mean proportions of errors were .013, .092, and .055 for same-stimulus, same-response, and different trials, respectively. The corresponding figures for the vocal-manual condition were .094, .032, and .070, respectively. In short, in the manual-manual condition, there are fewer errors on same-stimulus trials, as usual, whereas this effect is reversed for vocal-manual trials. This interaction was highly significant, $F(2,24) = 136.0$, $p < .001$, $MS_e = 0.0002$.

In half of the blocks of this experiment, all trials involved manual choice responses. As expected, a substantial repetition effect appeared on the vocal/manual blocks where the subject made a manual response on each trial. This repetition effect produces a benefit for same-stimulus trials, but not for same-response trials, nicely replicating the findings of Experiment 1, to which the design was very similar. On those blocks where the tasks alternated, when the stimulus requiring manual response followed an identical stimulus (but that stimulus was named aloud), no facilitation appeared, and the interaction of condition by repetition was significant. This result indicates that the repetition effects observed in the previous experiments are not produced by repetition of the perceptual identification of the stimulus. This result clearly supports the conclusion that these repetition effects reflect a speedup in response selection, not perceptual identification. This fits with the conclusions suggested initially here based on additive-factors experiments. Given the results of the first five experiments, this indicates that the shortcut model—postulating transient strengthening of links that directly connect low-level stimulus codes with the response—is essentially correct.

Naturally, the conclusion that these repetition effects are postperceptual should not be taken to deny that under certain circumstances, repetition effects may be perceptual. As noted initially here, the present discussion pertains exclusively to speeded-choice tasks with simple familiar stimuli and easy responses. Using much more complex and less frequent stimuli (such as words), repetition effects have been obtained using accuracy measures in tachistoscopic word-identification tasks, for example, and those effects may well originate in the perceptual identification stage. It is possible that differences in the familiarity of stimuli and the degree of perceptual difficulty could change the locus of the effects of repetition.

Finally, the fact that the lag -2 repetition effects are approximately the same size for the two conditions has interesting implications for the cause of the decline of repetition

effects from trial to trial. The comparison of lag and RSI effects in Experiments 1 and 3 indicated that intervening trials reduce the effects a great deal compared with the sheer passage of a corresponding amount of time. The results of this experiment tell us that this reduction is not dependent on the subject's making a manual response, nor even on the subject's performing the same task. However, the results cannot tell us whether it is simply perceiving an intervening stimulus that reduces the effect, or perhaps simply performing any kind of task.

Experiment 7: Repetition and Response Hand

The first five experiments demonstrated that the repetition effect does not "transfer" well to new stimuli assigned to the same response, even when these stimuli belong to the same conceptual category. However, the preceding experiment showed that it is not sufficient to produce the repetition effect to simply repeat the same stimulus on two consecutive trials. Together, then, these results argue for the view that repetition produces a stimulus-specific speedup in response selection, as suggested by the response selection shortcut model. The present experiment attempts to determine the extent to which the repetition effect depends on the exact identity of the responses selected on two consecutive trials. In the preceding article (Pashler & Baylis, 1991), it was found that the practice effect transfers almost perfectly from one speeded-choice task to another one in which the manual responses are spatially homologous, but executed with the other hand. The same could be true of the repetition effect, if the response-selection shortcuts lead to the selection of an abstract spatial specification of the response rather than to specific motor commands. However, just as the repetition effect is more stimulus specific than the practice effect, it might also show a higher degree of specificity to particular motor actions. Again, the method used here parallels that of the corresponding experiment in the practice studies.

Method

Twenty-two subjects participated. The stimuli were presented as in Experiment 1, with a noncategorical mapping. The stimuli "4" and "P" were mapped onto the leftmost key, "2" and "V" onto the middle key, and "8" and "K" onto the rightmost key. The right-hand response keys were ";", ".", and "/" while the corresponding left-hand response keys were "z", "x", and "c." All responses were made with the first three fingers of the response hand. On half of the blocks of trials, subjects were instructed to respond with their right hand only. On the other blocks of trials, subjects were instructed to alternate between left and right response keys. Right-hand blocks alternated with alternating hand blocks. Half of the subjects began with a right-hand block, while half began with an alternating hand block. The interval between trials was 1,000 ms.

Results and Discussion

Mean reaction times. Figure 10 presents the mean correct manual response times as a function of transition type (i.e., the relationship of the preceding stimulus to the response in question) and block type (alternating hand or fixed hand). As Figure 10 shows, subjects were faster for fixed-hand than alternating-hand responses (564 ms vs. 648 ms). $F(1, 21) =$

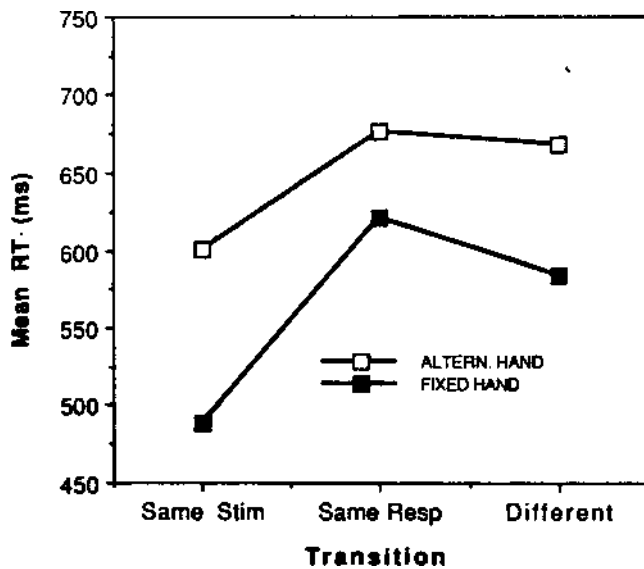


Figure 10. Mean response times (RTs) in Experiment 7 as a function of (immediate) transition type. (Stim = stimulus; Resp = response; Altern. = alternating.)

37.8, $p < .001$, $MS_e = 6130$. This effect could reflect faster right-hand responding given that in the fixed-response hand blocks, it was always the right hand that responded. Of course, it could also reflect faster responding as a result of better preparation with the fixed assignment to hands. In either case, this finding is of no particular interest for present purposes. As the graph shows, the repetition effects were reduced in the alternating-hand condition, and the interaction of block type with condition was significant, $F(2, 42) = 22.5$, $p < .001$, $MS_e = 420$.

Error rates. With the right-hand responses, the mean proportions of errors were .012, .060, and .041 for same-stimulus, same-response, and different transitions, respectively. The corresponding figures for the alternating-hand responses were .038, .059, and .050, respectively. The overall increase in errors for the alternating-hand condition was significant, $F(2, 42) = 16.5$, $p < .001$, $MS_e = 0.0008$. The interaction of this factor with repetition condition was also significant, $F(2, 42) = 7.6$, $p < .002$, $MS_e = 0.0003$.

The results indicate that the repetition effect shows a fairly high degree of response specificity in contrast to the practice effect (Pashler & Baylis, 1991, Experiment 5). It appears, then, that repetition effects differ from practice effects in providing facilitation that is more specific at both the stimulus and response ends.

General Discussion

The experiments reported in this article were designed to address a number of basic unanswered questions concerning the intertrial repetition effects in speeded-choice tasks, and their relationship to practice effects found in the same tasks. The overall results of these studies support several conclusions concerning the source of repetition effects and, together with

the results of the accompanying article (Pashler & Baylis, 1991), they allow us to make some tentative conclusions about the relationship between practice and repetition effects.

As expected, sizable repetition effects were observed for same-stimulus trials, usually exceeding 100 ms. The first five experiments varied the degree to which the stimuli assigned to a given response also belonged to a common conceptual category. In Experiment 1, the items were deliberately chosen so that they did not belong to a common conceptual category, and the results showed no benefit for same-response trials; in fact, there was actually some slowing. When the items did belong to a common conceptual category (e.g., letters, digits) in the second and third experiments, some benefit for the same-response trials appeared. However, this benefit was very modest compared with the benefit for the same-stimulus trials. In Experiments 4 and 5, the items assigned to any given response differed even more superficially: in case (Experiment 4) and color (Experiment 5), where both case and color were irrelevant to the task instructions. The results showed rather little benefit for same-response trials in Experiment 4, but in Experiment 5, the same-response trials were almost as fast as same-stimulus trials (i.e., color made little difference to the repetition effect).

In general, then, the results show that the repetition effect is very stimulus specific. This immediately rules out a response-execution locus for the effect, along with the highest link model sketched initially here, according to which the repetition effect originates in a transient facilitation of a link between the highest level category node and the response. These results were consistent with either a purely perceptual locus for the repetition effect, or with the shortcut model, postulating strengthening of links between low-level stimulus attributes and the response category.

Experiment 6 attempted to tease apart these possibilities by testing a prediction of the perceptual-locus hypothesis. According to that hypothesis, it should be sufficient to produce a same-stimulus repetition effect to simply repeat the stimulus on two trials that both require identification of that stimulus, even if the response mapping is different in the two tasks. By contrast, the shortcut model predicts that this will eliminate the repetition benefit. The repetition effect was abolished, supporting the shortcut model. Thus, the effects of repetition in this kind of task seem to arise from a speedup of the response-selection process. This conclusion confirms Welford's (1976) suggestion that the speedup originates, as he put it, in the stage of mentally "translating" between stimulus and response. In the case of the practice effect, evidence for a locus in the translation stage comes most directly from the finding that when the same set of stimuli are mapped onto the same set of responses, but with a shuffling of the mapping, the practice effect is abolished (Pashler & Baylis, 1991, Experiment 4).

The final experiment indicated that the effects of repetition are somewhat specific to the actual effector used in making the response. Subjects performed a speeded-choice task under one of two conditions: making all responses with either the right hand or alternating hands but keeping the mapping from stimulus to relative locations the same. This nearly eliminated the repetition benefit. Given the preceding results, then, this

supports a modification of the shortcut model, which postulates that repetition strengthens transient links that facilitate particular motor responses as well as a more abstract spatial-response specification.

Repetition and Practice Effects Contrasted

Taken together, the findings of the experiments reported here and those reported in the previous article (Pashler & Baylis, 1991) indicate that both the practice effect and the repetition effect originate almost entirely from a speedup of response selection. This might seem to suggest that the two effects could have a common source (or, to put the point differently, that the traces underlying the repetition effects might be cumulating to produce the practice effect). As pointed out initially here, if repetition effects do not entirely dissipate, then they must contribute something to the practice effect, and parsimony would suggest an explanation of practice in terms of the buildup of (weakened) repetition effects. However, the present work argues against this hypothesis. The results show that the set of variations in stimuli and responses that preserve the repetition effect is narrower than the set of variations across which the practice effect transfers. Thus, with a categorical mapping, the practice effect transfers very well to new stimuli drawn from the trained categories (Pashler & Baylis, 1991, Experiment 1). By contrast, in Experiment 2, using the same categorical mapping, the repetition effect was largely stimulus specific (i.e., little "transfer" of the repetition effect was observed to stimuli drawn from the same category as the preceding stimulus). The same conclusion applies when the different stimuli mapped onto a given response differ only in case (Experiment 4). Similarly, it appears that the repetition effect is fairly specific to the actual motor response involved, whereas the practice effect reflects strengthening of pathways selecting an abstract, spatially coded response specification. The practice effect transfers very well to a new mapping in which the stimuli are mapped homologously onto the opposite hand from the one that was trained. By contrast, in Experiment 6, the repetition effect is substantially attenuated when different but spatially homologous responses must be selected on consecutive trials.

Figure 11 illustrates the tentative account of repetition and practice effects that emerges from these studies. We propose that the repetition effect is caused by creation and transient strengthening of links that shortcut the response-selection stage, by translating directly from fairly early stimulus representations all the way to fairly specific responses. By contrast, the practice effect results primarily from a gradual strengthening of the central response-selection stage. This stage translates from a categorical representation of the stimuli mapped onto a given response and yields an abstract spatial representation of the appropriate response. At the same time, the practice studies also indicated that shortcut links existed, because when the mapping from stimuli to responses was shuffled, using a categorizable mapping, the old items were responded to more slowly than the new items from the trained categories (Pashler & Baylis, 1991, Experiment 4). This was presumably a result of response competition caused by links

from individual stimuli to the (now erroneous) responses they were trained with.

It should be noted that these differences between practice and repetition effects are still consistent with the possibility that the practice effect is caused by the accumulation of a subset of the traces underlying repetition effects. For instance, it could be that the traces linking more peripheral codes (the peripheral shortcuts) disappear rapidly, while the links mediating more central response-selection effects decay more gradually, and thus accumulate to produce the practice effects.

Concluding Observations

The results of the studies reported here and in the accompanying article (Pashler & Baylis, 1991) make some progress toward characterizing both short- and long-term changes that arise as subjects perform trials of a speeded-choice task. The results implicate the response-selection stage in all these changes (confirming Welford's suggestions about both), but suggest that long-term and transient effects differ in how they affect response selection. Although the conclusions reached here go well beyond the findings of previous studies of speeded-choice tasks, it is possible to see some of them as instantiating two very general principles of associative learning and memory. The first principle we have in mind is that the associations most easily strengthened by repetition are just those that are weaker to start with. The fact that the effects observed here are focused on response selection may not be a brute fact about speeded-choice tasks, but rather a consequence of this general principle. Speeded-choice tasks of the kind employed here use very familiar stimuli and very simple responses: For such tasks, there may be little room for an improvement in the stages of processing involved in perceptual identification, categorization, and response organization and execution. By contrast, the response-selection stage relies on a previously unfamiliar and essentially arbitrary mapping, and thus it may gain the most from any given amount of practice.

The second general principle that these results may instantiate is that more abstract information typically decays more slowly in memory. Some very well-known examples of this include the levels of processing phenomenon in free recall with words (Craik & Lockhart, 1972), and the finding that, in memory for prose passages, superficial information is lost more rapidly than underlying prepositional content (Sachs, 1967). Although this generalization has been challenged (e.g., Kolers, 1976), it nonetheless appears to fairly summarize many findings. The conclusions reached here regarding the locus of practice and repetition effects may be seen as a special case of this generalization: Those traces apparent at a shorter duration (producing the repetition effect) appear to include particular surface features of stimuli and responses as well as more abstract information, whereas the traces apparent after longer delays (yielding the practice effect) appear to include only associations between more abstract representations of stimuli and responses. On the surface, the experiments we reported here appear far removed from such "memory phenomena." Nonetheless, it is possible that simple generalizations about associative learning may characterize things as

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Harvey Appointed Editor of *Contemporary Psychology*, 1992-1997

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