Cognitive inhibition in selection and sequential retrieval

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Inhibitory models of working memory efficiency (Engle, 1996; Zacks & Hasher, 1994) assert that individual differences in working memory reflect the efficiency of inhibitory processes that exclude irrelevant information and suppress no-longer-relevant information. The present study examined the implication that these two inhibitory processes operate at consistent levels of efficiency within individuals by examining the correlation between two cognitive inhibition effects, negative priming and negative error priming. Negative priming involves slower response to a probe-trial target that was used as a to-be-ignored distractor on the immediately preceding prime trial. Negative error priming is the phenomenon that errors in a sequence of simple arithmetic trials are unlikely to involve the correct answer to the preceding problem. Participants received distractor-target pairs of simple addition problems and were required to produce the target problem sum. Negative priming was observed for prime distractors, whereas negative error priming was observed in connection with previous targets but not distractors. Consistent with the assumptions of these working memory models, the magnitudes of the two effects were significantly correlated.

Inhibition processes are ubiquitous in the mammalian brain (Gottlieb, 1988), and cognitive psychology has recently turned its attention to discerning the functional role of these processes in cognitive performance. *Inhibition* refers to the suppression of neural activity or, in cognitive terms, suppression of a mental representation or action. The efficiency of inhibition is hypothesized to be an important source of individual variability underlying differences in cognitive and social performance across age (Bjorklund & Harnishfeger, 1990; Harnishfeger, 1995; McDowd, Oseas-Kreger, & Filion, 1995) and various psychopathologies, such as schizophrenia (Beech, Powell, McWilliam, & Claridge, 1989) and ADHD (Barkley, 1997; Logan, Schacher, & Tannock, 1997). For example, the theory that inefficient inhibition underlies cognitive differences in childhood (Bjorklund & Harnishfeger, 1990) and aging (Zacks & Hasher, 1994) successfully predicts performance variations across age groups in such diverse tasks as inhibition of the startle eyeblink (Filion & McDowd, 1993, cited in McDowd et al., 1995), habituation of the orienting response (McDowd & Filion, 1992), reading comprehension (Con-

nelly, Hasher & Zacks, 1991; Hamm & Hasher, 1992), directed forgetting (Zacks, Radvansky, & Hasher, 1996), and negative priming (Hasher, Stoltzfus, Zacks, & Rypma, 1991; McDowd & Oseas-Kreger, 1991).

More specifically, inhibitory processing is hypothesized to underlie individual differences in working memory. Engle and his colleagues (Conway & Engle, 1994; Engle, 1996; Rosen & Engle, 1997) propose that individual variation in the suppression of distracting information underlies differences in working memory capacity (known as the *inhibition-resource hypothesis*). Similarly, Hasher and Zacks (1988; Stoltzfus, Hasher, & Zacks, 1996; Zacks & Hasher, 1994) propose a model of working memory wherein inhibition operates (1) to prevent task-irrelevant information from gaining access to working memory and (2) to rapidly suppress information that was once relevant but has become irrelevant as processing proceeds (e.g., information from previous trials).

The implication in these inhibitory efficiency models of working memory is that a general inhibitory process controls access to working memory, suppressing both distracting information and no-longer-relevant information. Each of these predictions has been tested separately, the suppression of distracting information using negative priming (Hasher et al., 1991; McDowd & Oseas-Kreger, 1991) and habituation (McDowd & Filion, 1992) paradigms, and the suppression of no-longer-relevant information by examining intrusion rates in memory retrieval studies (De Beni, Palladino, Pazzaglia, & Cornoldi,

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1998; Hamm & Hasher, 1992; Hartman & Hasher, 1991; Lorch & Reimer, 1997). These studies generally indicate that individuals with greater working memory capacity show stronger inhibitory effects. However, if working memory efficiency is controlled by such processes, presumably both of these inhibitory processes operate simultaneously, with consistent efficiency within an individual. The purpose of the present study was to examine the joint operation of these processes within a single task in order to test this prediction.

Theoretically, distractor inhibition and suppression of no-longer-relevant information (i.e., self-inhibition) involve different "targets of inhibition" and therefore may be accomplished by different processes (Arbuthnott, 1995; Kramer, Humphrey, Larish, Logan, & Strayer, 1994). Inhibitory models of working memory imply either that a single process operates to exclude both types of information or that separate processes operate with a similar level of efficiency in the working memory of an individual. A means of investigating this overall assumption is to examine whether performance is consistent for an individual across paradigms that measure these two types of inhibition. The present study used this strategy to examine the consistency of processing between two such inhibitory effects, negative priming (Tipper, 1985) and negative error priming (Arbuthnott, 1996; Campbell & Clark, 1989).

Negative Priming and Negative Error Priming

Our primary goal in the present study was to examine the correlation between negative priming and negative error priming effects. *Negative priming* is observed in selective attention tasks that require participants to respond to a target stimulus while simultaneously ignoring a distractor stimulus (see Fox, 1995, May, Kane, & Hasher, 1995, and Neill, Valdes, & Terry, 1995, for reviews). The aftereffects of ignoring the distractor are then examined in the subsequent trial. Specifically, response to a target that appeared as the distractor in the previous trial (i.e., an ignored repetition condition) is slower or less accurate than target response in a neutral control condition (i.e., no relationship between stimuli in consecutive trials). Conversely, *negative error priming* (henceforth, NEP) is observed in a mental arithmetic task that requires no ostensible divided attention. NEP emerges in connection with the errors that participants produce when required to vocalize answers to a series of simple arithmetic problems (e.g., $3 + 5 = ?$, $2 + 4 = ?$, etc.) under speed pressure. Several experiments have demonstrated that the specific error produced on a given trial (e.g., $2 + 4 = \text{"seven"}$) is unlikely to involve the correct answer to the preceding problem (Arbuthnott, 1995, 1996; Campbell, 1991, 1994; Campbell & Clark, 1989; Campbell & Tarling, 1996). For example, responding "seven" to $2 + 4$ is less likely if the immediately preceding problem was $2 + 5$ than if it was $3 + 5$. In fact, relative to expected error-matching rates, the probability that an error matches the correct answer from the immedi-

ately preceding trial is often significantly below chance. This NEP effect apparently indicates that people inhibit the problem or answer retrieved on each trial, presumably to reduce interference effects on subsequent trials. The interpretation of NEP as an inhibitory effect is supported by the finding that, when the identical problem is repeated in a series of arithmetic trials, the magnitude of repetition facilitation tends to increase over several trials (Campbell & Arbuthnott, 1996). This would be expected if problems or answers were inhibited on each trial and the strength of the inhibitory effect decayed over the next several trials.

These two effects reflect the hypothesized inhibitory processes in Hasher and Zacks's (1988; Stoltzfus et al., 1996) model of working memory. Negative priming reflects the suppression of irrelevant information, and NEP reflects the efficient clearing of no-longer-relevant information from working memory. If it is the case that both of these types of distractor suppression operate using a single process, negative priming and NEP effects should show some consistency within an individual (i.e., the efficiency of their cognitive inhibitory processes should influence the magnitude of both effects in a consistent direction). To test this prediction in the present study, we examined both negative priming and NEP in a single task.

This comparison of effects may also contribute to the discussion of mechanisms underlying negative priming. Two current theories of negative priming hypothesize that the effect reflects either attentional inhibition (Tipper, 1985) or episodic retrieval processes (Neill et al., 1995), or both (Kane, May, Hasher, Rahhal, & Stoltzfus, 1997). The episodic retrieval account suggests that stimulus similarity between trials causes re-retrieval of a previous episode, and, when the role of the common stimulus varies on the current and retrieved trials (i.e., the distractor in the prime trial and the target in the current trial), response is slowed while the confusion is resolved. If NEP correlates with negative priming, this would provide additional evidence regarding this issue. As discussed above, inhibitory theories of negative priming and NEP predict a correlation between the effects on the basis of inhibitory similarity; however, if negative priming reflects episodic retrieval confusion, the basis of such a correlation is less clear. This issue is discussed more thoroughly following consideration of the results. However, because the primary interest in this study was inhibitory processes, we used the procedures recommended by Kane et al. (1997) to minimize the influence of episodic retrieval on negative priming effects. Kane and his colleagues contend that negative priming reflects inhibitory processes, except in situations where retrieval of a previous trial clearly facilitates performance. Such situations include consecutive repetition of target stimuli (i.e., an attended repetition condition), target stimuli that are difficult to process (e.g., degraded or very brief presentation), precuing of trials, or yes-no decision responses. Our task did not include any of these factors

likely to promote episodic retrieval, and responses were spoken aloud.

Task and Predictions

To examine the consistency of negative priming and NEP within individuals and test the assumption that both processes operate simultaneously, we devised a task that could incorporate both effects: a selective attention task with mental arithmetic stimuli. On each trial, two addition problems were presented, with one problem (two operands) presented in red and the other problem presented in green. Participants added the two digits in one of the colors (counterbalanced across participants) and vocally named the sum. Two ignored repetition conditions were used: For consecutive trials, the distractor problem in the prime trial (e.g., distractor 2+5, target 3+1) became the target problem in the probe trial (e.g., distractor 3+3, target 2+5; ignored repetition condition). Alternatively, the correct sum to the distractor problem in the prime trial (e.g., distractor 2+5, target 3+1) became the correct sum for the target problem in the probe trial (e.g., distractor 5+1, target 3+4; ignored answer condition). To accommodate the ignored answer condition, we used small addition problems that have shown automatic sum activation. There is considerable evidence that the presentation of arithmetic problems activates candidate answers in an associative memory network of number facts (Campbell & Graham, 1985; Geary, Widaman, & Little, 1986; Miller & Paredes, 1990; Miller, Perlmutter, & Keating, 1984) and that this activation is automatic for small arithmetic problems (e.g., sums less than 10; LeFevre, Bisanz, & Mrkonjic, 1988), at least in single-problem presentation situations. If negative priming is observed for semantic associates of the distractor (i.e., problems with the same sum), then response should be slower for both ignored repetition conditions than for a control condition with no similarity between problems in the prime and probe trials.

To summarize, the purpose of the present investigation was to explore whether negative priming and NEP are correlated. Negative priming was measured by comparing performance in the ignored repetition conditions with performance in the control condition (trials with no common stimuli on consecutive trials). NEP was measured by counting the frequency of perseveration errors (i.e., matches between error answers and the answer for the previous trial) and comparing this frequency to the number of such matches expected by chance. Both effects were observed at a significant level, allowing a calculation of the correlation between the magnitude of the two effects. If the two effects reflect a common mechanism, we would predict a positive correlation, since both would reflect the efficiency of cognitive inhibition for each individual. Although the question of common mechanism cannot be definitively answered by such a strategy, lack of correlation of the two effects would disconfirm the predictions of theories involving a general-

ized inhibitory mechanism (e.g., Engle, 1996; Zacks & Hasher, 1994).

The present design also allowed us to examine the longer term priming effects of ignored distractor stimuli. The negative priming effect suggests that some processing of distractor stimuli operates in visual selection tasks. Are the effects of this distractor processing evident beyond consecutive trials? To examine this question, we used an analysis of error matches to previous target or distractor problems beyond consecutive trials (i.e., positive error priming). Foreshadowing the results, matches between error answers and previous target answers indicated a typical curvilinear error priming function, with matches below chance for the immediately preceding trial (i.e., NEP), but then rising above chance over a range of about 2–10 trials (Campbell & Arbuthnott, 1996; Campbell & Clark, 1989). However, error matches to previous distractor answers occurred at chance rates. This finding indicates that, although distractor problems cause interference on consecutive trials (negative priming), they show no residual effects in terms of error priming.

METHOD

A selection task similar to those employed in previous identity-based negative priming studies (e.g., Tipper & Driver, 1988; Tipper, Weaver, Cameron, Brehaut, & Bastedo, 1991) was devised using pairs of simple addition problems. The digits 1 to 5, with sums from 4 to 8, were employed. The participants answered one of the equations, cued by color, as rapidly and as accurately as possible. Trials were arranged in prime–probe pairs such that the distractor in the prime trial sometimes became the target in the probe trial (i.e., ignored repetition condition). The prime–probe distinction was not drawn to the participants' attention, and the same production task and between-trial timing were used throughout the experiment.

The prime–probe stimuli represented three conditions: (1) an ignored repetition condition, (2) an ignored answer condition, and (3) a neutral control condition (see Figure 1 for examples). The target in the ignored repetition condition was the same addition problem (same operands in the same order) used as the distractor problem in the prime trial. This condition tested most strongly whether the inhibition effect evident in naming selection tasks could be observed in a mental arithmetic task involving retrieval of sums. The target sum for the ignored answer condition was the same as the distractor problem sum in the prime trial, but the prime distractor and probe target involved two different problems (e.g., 2+5 and 3+4). The ignored answer condition was included speculatively, to explore whether negative priming would be observed for an internally generated distractor (i.e., the answer to the distractor problem that was not presented perceptually), similar to the suppression of an irrelevant meaning of a polysemous word (Gernsbacher & Faust, 1991; Simpson & Kang, 1994). The control condition involved no relationship between target and distractor problems in prime and probe trials. In all three conditions, every attempt was made to minimize feature similarity within a target–distractor display, within the constraints imposed by balancing stimuli between prime and probe distractor and target conditions.

Participants

Sixty-four participants (34 women, 30 men) were recruited from the University of Saskatchewan Department of Psychology partic-

Negative Priming Manipulation

<u>Prime Trial</u>		
Ignored Repetition	Ignored Answer	Control
3	4	2
<i>1 + 5</i>	<i>3 + 3</i>	<i>3 + 4</i>
4	1	2
<u>Probe Trial</u>		
	4	
	1 + 5	
	4	

Note: Target problems are shown in Bold and Distractor problems are shown in *Italic*.

Negative Error Priming: Response Possibilities to Probe Trial target (1+5)

Correct Answer: 6

Error matching prime trial target (perseveration)

Ignored Repetition:	7
Ignored Answer:	5
Control:	4

Error matching prime trial distractor

Ignored Repetition:	not possible (correct answer)
Ignored Answer:	not possible (correct answer)
Control:	7

Figure 1. Sample stimulus display.

ipant pool. They ranged in age from 17 to 45 years ($M = 24.7$ years) and reported normal color vision and normal or corrected-to-normal vision. Each was paid \$4 to participate.

Apparatus and Stimuli

Stimuli were presented using an IBM-compatible personal computer connected to a monitor that displayed green, red, and white characters against a black background. A lapel microphone connected through a relay switch to the computer controlled a software clock accurate to ± 1 msec. Incorrect answers and verifications of correct answers were entered by the experimenter.

The stimuli were 19 addition problems in the range from 1+1 to 5+5, excluding those problems for which an answer could not be

obtained from two different problems in the range (i.e., 1+1, 1+2, 4+5, 5+5). Probe trials for all three prime-probe conditions consisted of the same target and distractor pairs, in order to balance the possible RT costs of distractor-target interference. Each problem appeared equally often as a probe and a prime and as a distractor and a target. Problems were presented in four blocks of 114 trials, for a total of 456 trials (228 prime trials and 228 probe trials). Within each block, each probe pair appeared three times, once in each prime condition. The order of probe problems was random, with the constraint that each was used once before any problems were repeated. Targets and distractors were cued by color (red and green), with half of the participants responding to each color.

Target problems appeared in either vertical or horizontal orientation, with a central "+" sign separating the operand digits (see Figure 1). For each trial, distractor problems appeared in the opposite color and orientation of the target problem (i.e., if the target problem was green and horizontal, the distractor problem was red and vertical). Orientation of targets was constrained such that the probe target problem always appeared in the same orientation as its prime distractor problem. This meant that target problem orientation always changed between prime and probe trials. Alternation of the orientation of target problems between probe trials and the subsequent prime trial occurred randomly. Target and distractor problems appeared equally often in each orientation.

Procedure and Design

This experiment employed a within-subjects design with three levels of the prime-probe condition (ignored repetition, ignored answer, or control). The participants were tested individually. Each was instructed to vocally name the sum of the red (or green) equation, ignoring the co-appearing green (or red) equation. Instructions stressed both speed and accuracy. A warm-up digit naming task was used to familiarize the participants with the temporal and pattern masking features of the experimental task.

Each trial began with a fixation dot that flashed on and off twice (a total duration of 1 sec). When the third flash would have appeared, the stimulus problems appeared on the screen with the "+" sign in the location of the fixation dot. The stimuli were presented for 350 msec, followed by a white pattern mask ("##") in the position of each digit. The mask remained on screen until the participant responded and was then immediately replaced by a stationary fixation dot, which, after a response-stimulus interval (RSI) of 2 sec, resumed the sequence. The participants were given a brief rest after each block of 114 trials. The entire testing procedure took approximately 40 min to complete.

RESULTS

Negative Priming

For each participant, mean response times (RTs) for correct answers were calculated for each of the 19 problems in each prime-probe condition, and then condition means per participant were computed as the mean of the problem means. RTs greater than 2.5 standard deviations (*SDs*) from each participant's mean for each condition were discarded as outliers (approximately 1.7% of prime trials and 2.0% of probe trials, equally distributed across conditions).

Mean RTs for probe trials in the three prime-probe conditions were submitted to a repeated measures analysis of variance (ANOVA). This analysis indicated a significant prime-probe effect [$F(2,126) = 4.96$, $MS_e = 1,103$, $p = .008$]. The ignored answer condition (mean RT = 761 msec, $SD = 86$ msec) did not differ from the control condition (mean RT = 762 msec, $SD = 83$ msec), but RTs in the ignored repetition condition (mean RT = 769 msec, $SD = 86$ msec) were slightly slower than RTs in both of the other prime-probe conditions (Tukey's HSD = 1.76). Thus, significant negative priming was observed in the ignored repetition condition relative to that in both other prime-probe conditions. The magnitude of the effect, although very small, was similar to that of negative priming effects in previous studies (e.g., Kane et al., 1997). The corresponding repeated measures ANOVA of error rates indicated no differences in accu-

racy among prime-probe conditions (3.1% for ignored repetition, 3.4% for control, 3.6% for ignored answer; $F < 1$).

NEP and Positive Error Priming

Despite the low error rate observed in this experiment (3.3% overall), a total of 1,626 errors were observed. Errors occurred about equally often on prime trials (790 errors) and probe trials (836 errors). Among the total set of errors, 1,582 (97.3%) involved correct answers to other problems tested in the experiment (i.e., answers 4 to 8). These matchable errors were the focus of the error priming analysis. Specifically, for each of these errors, we searched previous trials (within the block that the error occurred) for problems with a correct answer that matched the error. Separate searches were conducted for matches to previous target answers and previous distractor answers (see Figure 1 for examples). The frequency of error-answer matches for each match type (target or distractor) at each "lag" (i.e., the number of trials between the error trial and the match trial) was tallied for each participant.

To obtain a baseline of expected error-answer matches, we analyzed the problem sequences received by our participants. The 260 sequences (64 participants $\times$ 4 blocks) constitute a large random sample of the pseudorandom sequences of problems and answers possible within the constraints of our experimental design. For each sequence, we counted the frequencies of all possible error-answer matches at all lags up to 16 trials and then summed these error $\times$ answer $\times$ lag frequencies over the 260 sequences. From these data, we calculated the relative frequency with which each matchable error was matched at each lag. The relative frequency estimates the chance probability that a specific error on a specific problem would match a previous correct answer at a given lag. For each participant, chance error-matching frequencies at each

Figure 2. Error priming: Deviations from chance match rates.

lag were then estimated by summing the relative frequencies associated with each of their specific errors. Chance matching frequencies were calculated separately for matches to previous target and distractor answers (i.e., match type).

Observed minus chance match frequencies for consecutive trials and across subsequent 3-trial lag ranges are presented in Figure 2.¹ The observed and chance frequencies for error-answer matches were submitted to a 2 (match type: target or distractor) $\times$ 2 (observed or chance matches) $\times$ 5 (Lag 1 and subsequent 3-trial lag ranges) repeated measures ANOVA. All main effects and interactions were significant in this analysis [$F(4,252) = 7.55$, $MS_e = 3.90$, $p < .001$, for the three-way interaction]. As can be seen in Figure 2, this three-way interaction reflects (1) no difference between observed and chance matches to previous distractor answers at any lag [greatest $t(64) = 1.66$; all $ps > .1$], (2) below-chance match rates for Lag 1 targets [$t(64) = -2.66$, $SE = 0.216$, $p = .01$], and (3) above-chance match rates for targets beyond Lag 1 [$t(64) = 5.07$, $SE = 0.119$, and $t(64) = 3.41$, $SE = 0.097$, for Lags 2–4 and 5–7, respectively; $p < .001$]. The curvilinear error priming function observed for target matches (see Figure 2) is typical of previous error priming results (Campbell & Arbuthnott, 1996; Campbell & Clark, 1989), suggesting that in this experiment only target problems, and not distractor problems, retained sufficient activation or unitization (Campbell, 1994) to influence subsequent errors.

The preceding analysis demonstrated that NEP was observed only for previous target answers, whereas

matches to previous distractor answers occurred at chance rates. However, a NEP effect in the distractor analysis may have been diluted and difficult to measure because errors on probe trials could be matched to previous distractor answers on only 33% of the trials, and then only one specific error could be matched (i.e., the answer for the control problem assigned to that target problem). For the other 67% of the trials, the distractor problem had the same correct sum as the probe target problem (i.e., the ignored repetition and ignored answer conditions; see Figure 1). Thus, an analysis including only errors on prime trials was conducted to verify that the pattern of results observed for Lag 1 was not due to sequential constraints associated with the negative priming manipulation. For this analysis, the observed match frequency for distractor answers ($M = .213$, $SE = .131$) did not significantly differ from the chance match frequency [$t(64) = 1.63$, $p = .107$]. It thus appears that the absence of NEP for distractor matches was not attributable to the error-matching constraints imposed by the negative priming manipulation.

Correlation of Negative Priming and NEP

To examine whether there is a relationship between these two inhibitory effects, a correlation of the magnitudes of negative priming (control minus ignored repetition RT) and target-trial NEP (observed minus chance match frequency) across the 64 participants was calculated (see Figure 3). It should be noted that both of these difference scores are derived from consistent baselines: the control condition for negative priming, and the

Figure 3. Correlation of NEP and negative priming.

chance match rates for each participant's specific errors for NEP (see Kane et al., 1997, note 3). A significant positive correlation was observed ($r = .24, p = .027$, one-way).² This positive correlation indicates that greater negative priming from ignored repetition trials was associated with fewer perseveration errors (i.e., lower Lag 1 error-matching rates). In other words, if both of these effects reflect the action of a cognitive inhibition process, the efficiency of the inhibitory process in any one individual varied consistently across the two effects.

DISCUSSION

The primary purpose of this study was to examine the consistency of distractor inhibition and self-inhibition effects within individuals. The results indicated significant negative priming and NEP effects and a positive correlation between the magnitude of the two effects. As well as supporting the predictions of inhibitory models of working memory, these results contribute experimental evidence to that provided by clinical assessment measures (Olson, 1989) and neuropsychological evidence (West, 1996) supporting the hypothesis that different types of cognitive inhibition are mediated by common or related mechanisms.

Episodic Retrieval

Before accepting this conclusion, however, the issue of the mechanism underlying negative priming must be addressed. The present results suggest that negative priming and NEP reflect processes that show consistent levels of efficiency within an individual. However, is this common process cognitive inhibition or episodic retrieval? The inhibitory explanations for negative priming and NEP effects are very similar: exclusion of irrelevant (i.e., distractor representations) or no-longer-relevant (i.e., previous answer) information from working memory. How would episodic retrieval operate to account for the two effects?

For negative priming, retrieval of the ignored-repetition prime trial would cause interference by stimulus role confusion (i.e., distractor vs. target), because the same stimulus is a distractor in the prime trial and a target in the probe trial. Evidence in support of this account of negative priming includes greater negative priming effects using manipulations that increase the discriminability of the prime trial from among the set of all previous trials, which would increase the probability of retrieval of that event (Kane et al., 1997; Milliken & Rock, 1997; Neill, 1997). It is argued that retrieval of the prime trial is promoted by the repetition of a stimulus element in the two trials. In the case of NEP, this would suggest that episodic retrieval would be especially likely for consecutive trials with a common operand (e.g., 5+2 and 5+3; known as *related problems*). However, for NEP, episodic retrieval of the previous trial would result in role consistency: The answer for the previous trial would serve the role of answer in the current trial, albeit an incorrect an-

swer. This would suggest that episodic retrieval of the previous trial would promote perseverative errors, especially for consecutive related problems. However, below-chance rates of perseverative errors are observed for consecutive related trials (Arbuthnott & Campbell, 1996).

Recently, Kane et al. (1997) presented evidence that negative priming could be caused by both attentional inhibition and episodic retrieval. They argued that episodic retrieval is evoked in only some experimental contexts, particularly those in which retrieval of previous episodes would benefit performance. For example, when stimuli are degraded, retrieval of previous related nondegraded trials can assist performance. Consistent with this account, when we include consecutive repetition of problems (or problems with the same answer) in the sequence of mental arithmetic trials, considerably more perseveration is observed, especially for consecutive trials that share characteristics with repetition trial pairs (Arbuthnott, 1996; Arbuthnott & Campbell, 1996). Including frequent immediate repetition in a sequential retrieval task increases the usefulness of retrieving previous events, and increased consecutive answer repetition (correct and incorrect) is observed. However, our data suggest that this repetition effect operates independently of self-inhibition processes, with frequent repetition evoking a strategy of repetition detection that is occasionally incorrect. The pattern of perseveration errors in these experiments suggests such a process of mistaken repetition detection. However, in trials that are unlikely to be mistaken for repetition trials, NEP is observed even in situations with high rates of repetition. Thus, episodic re-retrieval and NEP likely reflect different underlying processes in mental arithmetic tasks (Arbuthnott, 1996).

The results of the present study, therefore, are most easily interpreted as evidence supporting the inhibition account of negative priming, at least under these task conditions. The positive correlation between negative priming and NEP suggests that they reflect processes with similar efficiency within individuals. This similarity is not easily attributed to episodic retrieval processes that cause interference for consecutive trials with regard to selection between target and distractor problems but do not simultaneously promote perseveration errors.

Representational Level of Negative Priming and NEP

On the basis of the significant correlation between negative priming and NEP, we have suggested that the two effects are mediated by common or related mechanisms. Given this, how can we reconcile the finding of significant negative priming in connection with prime distractors, while we observed no NEP from prime distractors? One possibility is that the same mechanism is at work in both situations, but the negative priming effect, measured in RT, is more sensitive than the NEP effect, measured in the identity of errors.

It is also possible that negative priming and NEP reflect suppression of different representational units.

Negative priming was observed only for ignored repetition trials in this task. This condition exactly repeated all features between the prime distractor and probe target problems: the same operands, in the same problem position, presented in the same orientation (i.e., vertical or horizontal). It is thus unclear from these data whether the observed negative priming reflects identity suppression or a combination of identity and location suppression. It is clear that this effect cannot be attributed entirely to location suppression, since all prime distractor problems (i.e., including the control condition) were presented in the same orientation as the probe target. But what is the representational unit that was suppressed?

Since selection could be performed on the basis of a consistent physical characteristic, it is possible that only the color of the distractor was encoded. This possibility is unlikely, however, given the significant negative priming effect for the ignored repetition conditions. Suppression of the answer representations can also be eliminated because we observed neither negative priming for ignored answer primes nor NEP for distractor sums. Another possibility is that suppression targeted the individual distractor operands, but not the distractor problem. This would be consistent with the observation that negative priming was observed for ignored repetition primes, since both operands in the probe target problem would be suppressed. We tested this possibility by conducting a post hoc analysis of a subset of seven control condition problems that had one common operand in the prime distractor and probe target problems (with that operand in the same position in both problems; e.g., prime distractor 5+2, probe target 3+2). For this analysis, performance on these problems was compared with performance on seven other control problems with similar target sum magnitude (e.g., prime distractor 4+4, probe target 2+3). If representations of the prime distractor digits were suppressed, this analysis should indicate slower response for prime-probe pairs with one repeated operand. This was not observed ($F < 1$). Thus, it appears that the negative priming effect did not reflect suppression of distractor operand representations in this study.

A fourth possibility is that the distractor problem unit, but not the unitized problem-answer unit, was suppressed. These data are most consistent with this possibility. If the unitized problem-answer unit was suppressed, we would expect to observe significant NEP for the distractor sum as well as the target sum. However, if only the distractor problem unit was suppressed, we would expect to observe the present pattern of results: (1) negative priming only for ignored repetition trials, and (2) no NEP associated with distractor sums. Despite previous research indicating automatic activation of sums for problems in this range (LeFevre et al., 1988), it appears that this may not have been the case in this dual-problem situation. Our results also appear to contrast with previous negative priming results that indicate activation of semantic information associated with distractor stimuli (e.g., Tipper & Driver, 1988). The reasons for the incon-

sistency between our negative priming situation and previous studies are not clear at this time. However, it may be that this situation parallels other findings in attention research that indicate that attentional selection can occur at multiple loci of processing, dependent on the task situation and processing resources available (e.g., Johnston & Heinz, 1978).

The pattern of results in the present study suggests that negative priming and NEP effects may operate on different representational levels in this mental arithmetic task. For negative priming, the suppressed unit was most likely the problem representation (or the problem-location combination). For NEP, the suppressed unit was either the target problem-answer unit or the target answer representation. This suggests that negative priming and NEP do not reflect precisely the same mechanisms (see Earles et al., 1997, and Kramer et al., 1994, for similar evidence of multiple inhibitory mechanisms). However, the magnitude of the two effects showed a significant correlation, suggesting some generalized inhibition capacity that operates across tasks.

Processing of Target and Distractor Problems

The use of both selective attention and error priming analyses within the same study allows a unique picture of the processing received by target and distractor stimuli. For this task, evidence about the accessibility of a problem and its sum is available from (1) the current trial, (2) the subsequent trial, and (3) several trials after a given retrieval. For target problems, sums were retrieved quite rapidly and accurately, despite the presence of distractor problems. On the subsequent trial, the retrieved target sum was apparently suppressed (i.e., significant NEP), and, for longer trial lags, the sums (or problem-answer units) remained activated above baseline levels, promoting their re-retrieval as errors (Campbell & Clark, 1989). The pattern for distractor problems is quite different. The significant negative priming effect for ignored repetition trials suggests that the distractor problem was encoded and that this representation remained less accessible on the following trial. However, distractor problems apparently had no influence on subsequent trials, except when all features of the problem were repeated. This pattern of results suggests that, although distractor problems were encoded, selective attention mechanisms protected subsequent memory retrieval processes from any long-term effect of this encoding.

Summary

The purpose of this study was to examine whether inhibitory effects observed in selective attention and sequential retrieval are correlated, as predicted by the theory that such processes control the efficiency of working memory. Negative priming and NEP were positively correlated for this group of 64 participants. This suggests that the capacity to reduce the influence of both distractor stimuli and previous responses is related. Thus, the

present results are generally consistent with the working memory models of Hasher and Zacks (1988; Zacks & Hasher, 1994) and Engle (1996). Different processes may control distractor inhibition and inhibition of no-longer-relevant information, but the efficiency of these processes seems to operate consistently within individuals.

We also examined the influence of distractor processing on memory retrieval over longer trial lags and observed no evidence of interference from distractors beyond consecutive trials. Target processing, however, continued to influence memory retrieval to a range of seven trials, consistent with previous observations in mental arithmetic tasks. The pattern of results observed in this study gives an interesting glimpse into the need for interference control in sequential memory tasks (Clark, 1992) and of the effectiveness of the inhibitory processes that deal with such interference.

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NOTES

1. To test the adequacy of this chance matching rate estimation, simulated error data were analyzed. For each of the 64 stimulus files used in the experiment, a computer program generated random but typical errors (i.e., within ± 2 of the correct answer). No significant differences between observed and chance error matching frequencies were observed in these simulated data. These simulated error data were subjected to the error priming analyses reported below, and none of the significant differences observed in the actual data were detected. We were thus confident that this method of calculating a chance matching baseline was adequate.

2. Examination of Figure 3 indicates one outlier with an extremely large negative priming score. Reanalysis excluding this participant resulted in a slightly reduced correlation ($r = .21$, $p = .047$, one-way).

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