Research Report

A RESOURCE ACCOUNT OF INHIBITION

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Abstract—*In a letter-naming task, a letter will be named more slowly if it was a distractor on the previous trial. This negative priming effect has been instrumental in renewed interest in inhibition. The present research explored whether inhibition is a result of controlled attention. When the naming task was performed under a mental work load, negative priming was diminished as work load increased. This finding suggests that inhibition is a product of controlled resources and that group differences in inhibition may result from differences in controlled attentional resources, not from inefficient inhibitory mechanisms.*

> . . . the substrate of the simple apperception process may be sought in inhibitory processes which, by the very fact that they arrest other concomitant excitations, secure an advantage for the particular excitations not inhibited. (Wundt, 1874/1904, pp. 317–318)

Excitation and inhibition have been part of explanatory concepts of the mind since the mid 1800s. Although the importance of excitation or activation has remained steady over the years, the importance of inhibition has waxed and waned (Diamond, Balvin, & Diamond, 1963). Bjork (1989) argued that inhibition was not commonly found in theories of cognition through the 1960s and '70s because the computer metaphor did not allow active dampening of information. He speculated that interest in inhibition has shown a rapid increase recently because of the increase in use of the brain as a metaphor for mind.

One of the reasons for the recent popularity of inhibition as an explanatory construct is the demonstration of negative priming (Greenwald, 1972; Neill, 1977). Tipper and Cranston (1985), for instance, showed subjects two letters, one red and one green, that were slightly superimposed. The task was to read aloud the red letter as accurately as possible. Tipper and Cranston argued that in order to select the red letter, the subject must actively inhibit the green letter.[1] If the representation of a given letter is thus inhibited, it should take longer to achieve activation of that representation on a subsequent trial, and the letter should be named more slowly. In fact, when the red letter on trial $n + 1$ had been the green letter on trial n, it was named more slowly than if the green letter on the previous trial had been a control letter. Evidence that a representation can be actively dampened has now come from a variety of tasks and subjects (for a review, see Neill, Valdes, & Terry, in press).

The negative priming effect has been used to argue for deficiencies in inhibition for a variety of groups. For example, Hasher and Zacks (1988) proposed that decrements in cognition as people age result from greater vulnerability to distraction and interference, which, in turn, result from decreased ability to inhibit information irrelevant to the task goal. In line with this idea, Hasher, Stoltzfus, Zacks, and Rypma (1991) found that older subjects showed no significant negative priming in the letter-naming task just described. Also, Gernsbacher and Faust (1991) found that people with poor language comprehension were less likely to inhibit the irrelevant meaning of a word or phrase than were people with good comprehension. In fact, differential ability to inhibit information has been proposed as an alternative to resource theories in explanations of developmental and individual differences in cognition (Brainerd & Reyna, 1989). These theories seem to conceptualize inhibition as a passive event, in a process akin to automatic spreading activation (Neumann & DeSchepper, 1992).

However, another possibility is that some individuals may not be able to inhibit because inhibition requires and consumes attentional resources and that there are developmental and individual differences in the availability of these resources. Support for the idea that inhibition is resource-limited can be found in an article by Nakagawa (1991), who showed that inhibition in a lexical decision task occurred only when the target was presented directly to the left hemisphere. More important, when the subject performed a concurrent shadowing task, inhibition did not occur at all.

In a previous study, we (Conway & Engle, 1994) had subjects learn various-sized sets of items and then perform a speeded recognition of the items in those sets (i.e., Sternberg, 1966). If items of different sets did not overlap, the slope of the set-size effect was the same for subjects measured to be high and low in working memory capacity. However, if each item was a member of two different sets, thus giving rise to response competition or interference at the time of retrieval, the slope of the set-size effect was steeper for subjects with low working memory than for those with high working memory. Our interpretation of this effect was that the former subjects did not have the attentional resources necessary to inhibit the connection between the cue and the irrelevant set and therefore performed a serial search of the tested set. Subjects with high working memory, in contrast, were hypothesized to be able to actively inhibit the link between the item and the irrelevant set cue.

The logic for the experiment reported here is that if inhibition requires attentional resources, then inhibition should be difficult when the subject is engaged in an attention-demanding task. Our prediction was that if subjects performed the letter-naming task while simulta-

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1. Other researchers (May, Kane, & Hasher, in press) have suggested that the green letter may be inhibited after the selection of the red letter. This argument is not relevant to the current study, but the reader should be aware that this issue is not resolved.

neously performing an attention-demanding recall task, the magnitude and the direction of priming would be determined by the size of the memory load. Specifically, we expected that as memory load increased, the negative priming effect would be reduced. The effect might even become facilitation as load increased.

The experimental condition had the purpose of measuring the priming effect as a function of mental work load. The control condition was tested on a different group of subjects and used the same events as the experimental condition. It provided a baseline, replicating previous studies of priming in the absence of a work load, and controlled for the possibility that the intervening words used in the experimental condition would reduce the negative priming effect independently of work load.

METHOD FOR EXPERIMENTAL CONDITION

Subjects

Forty-five subjects performed the task. All subjects were undergraduate students at the University of South Carolina, were tested individually, and received course credit for their participation.

Procedure

Each subject performed 300 trials (five blocks of 60 trials each) in which a red and a green letter appeared somewhat superimposed on the computer screen. Subjects were told to name the red letter and to ignore the green letter. They were also told that words would be presented periodically on the screen and they should remember the words for later recall but not say them aloud.

Half of the trials were prime trials and half were probe trials. One third of the probe trials (i.e., 50 trials) were *inhibition trials*, meaning that the red letter had been the green letter on the previous trial. Two thirds of the probe trials (i.e., 100 trials) were *control trials*, meaning that the red letter was not the same as either the red or the green letter on the previous trial.

A complete set of trials proceeded as follows (see Fig. 1). An asterism was presented for 750 ms, followed by a prime display of two letters for 150 ms. Another asterism was presented for 750 ms, followed by a probe display of two letters for 150 ms. This pair of prime and probe trials was assumed to be performed under *load 0* because the subject had not yet been presented with a word for later recall. After the probe display, the first to-be-remembered word appeared for 750 ms, followed by a prime display for 150 ms. Another asterism was presented for 750 ms, followed by a probe display for 150 ms. This pair of prime and probe trials was performed under *load 1* because the subject had one word to remember for later recall. This process continued until after the fifth probe display, at which point the word "recall" appeared on the screen. The subject was to name the four words in correct order out loud. Latency to name a letter was measured from presentation of the letter until the oral response activated a speech trigger. This latency was recorded by the computer, and the experimenter recorded letter-naming accuracy as well as recall accuracy for the words.

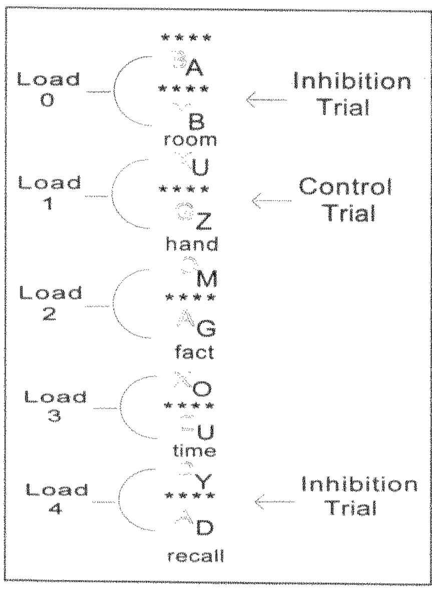

Fig. 1. Example of a complete set of trials. The dark letters represent red letters, and the double-lined letters represent green letters.

Materials

Ten letters were used as stimuli. The letters were divided into two pools (*A, M, X, Y, Z* and *B, D, G, O, U*). In each display, a letter was never paired with another letter from the same pool. The stimulus list was designed in the following manner. Each letter appeared as a red probe 15 times (150 probe trials) and was paired with each member of the other pool three times ($5 \times 3 = 15$). These letter pairs were then randomized with the following constraints: (a) One third of the probe trials were inhibition trials (the red letter had been the green letter on the previous trial) and the rest were control trials (the red letter was different from both the red and the green letter on the previous trial); (b) for all of the prime trials, the red letter was different from the red and green letters on the previous trial; (c) inhibition trials were counterbalanced across memory load, such that there were 10 inhibition trials per load condition; and (d) control trials were counterbalanced across memory load, such that there were 20 control trials per load condition.

The experiment was run on an IBM PS/2 with VGA monitor using Micro Experimental Laboratory (MEL; Schneider, 1988). Subjects spoke into a hand-held microphone connected to a MEL response box.

METHOD FOR CONTROL CONDITION

Subjects

Forty-six subjects performed the task defined as the control condition.

Procedure

The procedure was identical to the experimental condition except the subjects were told to ignore the words that were to be recalled by the subjects in the experimental condition. Instead of "recall," the word "rest" was presented for 10 s.

RESULTS

Eight subjects were excluded from the analyses for the experimental condition and 9 from the control condition because they reported being aware of the relationship between prime and probe letters on inhibition trials. The dependent measures of greatest interest were naming time and naming accuracy on probe trials and, in the experimental condition, recall accuracy.

A mean was derived for each subject's control trials and inhibition trials by averaging the five trial block medians. The priming effect is reflected in the difference between the mean for the control trials and the mean for the inhibition trials. The results are shown in Figure 2, with the priming effect for the control condition as the leftmost bar and the priming effect for the experimental condition as a function of load. For the control condition, letter naming was slowed by an average of 18 ms if the letter being named was the rejected letter on the previous trial. This value corresponds closely with the magnitude of negative priming observed in earlier research (Tipper & Cranston, 1985).

In the experimental condition at load 0, the magnitude of negative priming was somewhat higher than in the control condition (−41 ms). However, priming decreased as load increased and became positive by load 3 (16 ms). This result supports the notion that attentional resources are necessary to accomplish inhibition and that if those attentional resources are not available, the rejected information may not be inhibited.

These conclusions were supported by analysis of variance (ANOVA) on the median naming times. The variables were trial type (inhibition, control) and memory load (0–4). Trials in which a naming error occurred were excluded from the analyses. Also, for the experimental condition, trials were excluded if the subject did not correctly recall the word that was presented prior to that trial. For instance, if the subject recalled only the first two words presented, naming time for the load 0, 1, and 2 conditions would be included in the analysis, but naming time for the load 3 and 4 conditions would be excluded.

For the experimental condition,there were main effects of trial type ($F[1, 36] = 6.59, p < .05, MS_e = 8{,}982$) and memory load ($F[4, 144] = 3.86, p < .05, MS_e = 20{,}335$). Furthermore, the trial-type-by-memory-load interaction was significant ($F[4, 144] = 3.20, p < .05, MS_e = 20{,}118$). For the control condition, there was a main effect of trial type ($F[1, 36] = 25.02, p < .05, MS_e = 8{,}197$), showing significant negative priming. We also tested for an effect of "memory load" in the control condition even though subjects did not recall the words that were presented between letter-naming trials. The effect of memory load was significant ($F[4, 144] = 4.02, p < .05, MS_e = 7{,}281$) but showed no systematic trend over the trials corresponding to memory load in the experimental condition. We also tested for an interaction between trial type and "memory load" to ensure that the corresponding interaction in the experimental condition was not due to the simple presence of the words between trials. This interaction was not significant ($F[4, 144] = 1.56, p > .10, MS_e = 6{,}743$), showing that the reduction in negative priming in the experimental condition was not an artifact of the presence of the words.

An analysis of mean naming accuracy showed no significant main effects or interactions for either condition. We also conducted a trial-type-by-memory-load ANOVA on recall accuracy in the experimental condition. The data on recall accuracy are shown in Table 1. There was no main effect of trial type ($F[1, 36] = 2.29, p > .10, MS_e = 0.05170$), but there was a main effect of load ($F[3, 108] = 57.31, p < .05, MS_e = 0.06446$), showing that recall was better for the words presented at the beginning of the list. The trial-type-by-memory-load interaction was not significant, $F < 1$.

One interesting question is what would be expected on probe letter-naming trials following a word that was not subsequently recalled. One possibility is that a failure to recall the word means that the subject allocated all available resources to previously presented words and none remained for either rehearsal of the words or inhibition of the distracting green letters. If this were the case, then the probe trials should show no negative priming effect on trials following a word that was not recalled. However, another possibility is that the word was not recalled because the resources were allocated to inhibiting the green letter for the probe trial that followed and were not used for rehearsal. If that were the case, then the probe trials should show a large negative priming ef-

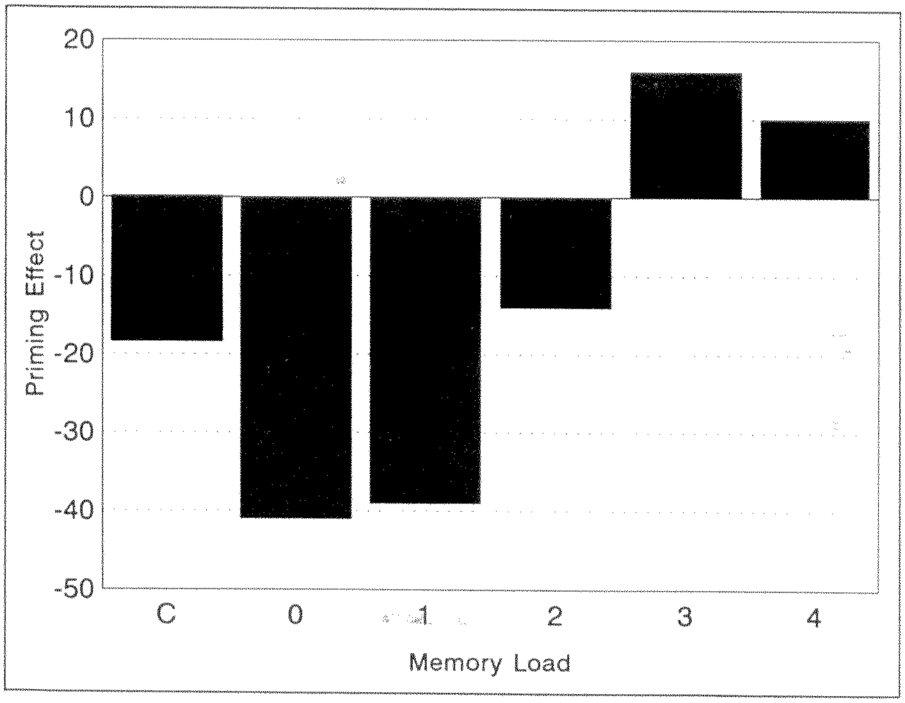

Fig. 2. Priming score (in milliseconds) for the control condition (C) and, as a function of load, for the experimental condition. The priming score was the difference between the mean naming time for control trials and the mean naming time for inhibition trials.

Table 1. *Percentage of naming and recall accuracy as a function of memory load*

Task	Load 0	1	2	3	4
	Experimental condition				
Naming	97	95	96	97	96
Recall	—	75	65	54	53
	Control condition				
Naming	97	97	97	97	98

fect, regardless of memory load. The results of this analysis clearly support the latter hypothesis. There was a 39-ms negative priming effect on probe trials following a nonrecalled word. This effect was reflected in the significant main effect of trial type ($F[1, 36] = 4.22$, $p < .05$, $MS_e = 50{,}818$). Further, trial type did not interact with memory load ($F[3, 103] = 1.73$, $p > .1$), showing that on probe trials following nonrecalled words, negative priming did not vary as a function of load. This finding suggests that the subject used the available attentional resources to inhibit the green letter instead of processing the recently presented word.

DISCUSSION

The data presented here show clearly that the magnitude and nature of the priming effect depend on the momentary attentional resources available to the subject. When the subject was not under a mental work load and named a letter that was previously rejected, that letter was named more slowly. As work load increased, there was less and less evidence that the unattended letter was actively suppressed. Further, naming of letters following the presentation of a word that was not subsequently recalled led to an average negative priming nearly identical to that found in the load 0 condition. This finding suggests that suppression of the unattended letter was a controlled attentional process that was less likely to occur as the recall task required more attention.

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REFERENCES

Bjork, R.A. (1989). Retrieval inhibition as an adaptive mechanism in human memory. In H.L. Roediger, III, & F.I.M. Craik (Eds.), *Varieties of memory and consciousness* (pp. 309–330). Hillsdale, NJ: Erlbaum.

Brainerd, C.J., & Reyna, V.F. (1989). Output-interference theory of dual task deficits in memory development. *Journal of Experimental Child Psychology*, *47*, 1–18.

Conway, A.R.A., & Engle, R.W. (1994). Working memory and retrieval: A resource-dependent inhibition model. *Journal of Experimental Psychology: General*, *123*, 354–373.

Diamond, S., Balvin, R.S., & Diamond, F.R. (1963). *Inhibition and choice*. New York: Harper & Row.

Gernsbacher, M.A., & Faust, M.E. (1991). The mechanism of suppression: A component of general comprehension skill. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*, 245–262.

Greenwald, A.G. (1972). Evidence for perceptual filtering and response suppression for rejected messages in selective attention. *Journal of Experimental Psychology*, *94*, 58–67.

Hasher, L., Stoltzfus, E.R., Zacks, R.T., & Rypma, B. (1991). Age and inhibition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*, 163–169.

Hasher, L., & Zacks, R.T. (1988). Working memory, comprehension, and aging: A review and a new view. In G.H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 22, pp. 193–225). New York: Academic Press.

May, C.P., Kane, M.J., & Hasher, L. (in press). Determinants of negative priming. *Psychological Bulletin*.

Nakagawa, A. (1991). Role of anterior and posterior attention networks in hemispheric asymmetries during lexical decisions. *Journal of Cognitive Neuroscience*, *3*, 313–321.

Neill, W.T. (1977). Inhibitory and facilitatory processes in attention. *Journal of Experimental Psychology: Human Perception and Performance*, *3*, 444–450.

Neill, W.T., Valdes, L.A., & Terry, K.M. (in press). Selective attention and the inhibitory control of cognition. In F.N. Dempster & C.J. Brainerd (Eds.), *New perspectives on interference and inhibition in cognition*. New York: Academic Press.

Neumann, E., & DeSchepper, B.G. (1992). An inhibition based fan effect: Evidence for an active suppression mechanism in selective attention. *Canadian Journal of Psychology*, *46*, 1–40.

Schneider, W. (1988). Micro Experimental Laboratory: An integrated system for IBM PC compatibles. *Behavior Research Methods, Instruments, and Computers*, *20*, 206–217.

Sternberg, S. (1966). High-speed scanning in human memory. *Science*, *153*, 652–654.

Tipper, S.P., & Cranston, M. (1985). Selective attention and priming: Inhibitory and facilitatory effects of ignored primes. *Quarterly Journal of Experimental Psychology*, *37A*, 591–611.

Wundt, W.M. (1904). *Principles of physiological psychology* (trans. of 5th ed.). New York: Macmillan. (Original work published 1874)

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