Memory & Cognition
1999, 27 (6), 1042-1050

The effect of memory load on negative priming: An individual differences investigation

ANDREW R. A. CONWAY
University of Illinois, Chicago, Illinois

STEPHEN W. TUHOLSKI
Southern Illinois University, Edwardsville, Illinois

REBECCA J. SHISLER
University of South Carolina, Columbia, South Carolina

and

RANDALL W. ENGLE
Georgia Institute of Technology, Atlanta, Georgia

The effect of a verbal (Experiment 1) and a nonverbal (Experiment 2) memory load on negative priming was investigated by employing a concurrent memory task with a letter naming task. Across both experiments, negative priming was reliable only under conditions of zero memory load, suggesting that the processes that contribute to negative priming are resource demanding and dependent on a domain-free resource pool. Individual differences in negative priming were observed, such that high working memory capacity subjects showed reliable negative priming whereas low working memory capacity subjects did not. The results suggest that the negative priming effect results from allocation of controlled attention and that individual differences in working memory capacity correspond to the ability to efficiently handle irrelevant information.

Negative priming refers to the finding that responses to stimuli that have recently been ignored are slowed (Dalrymple-Alford & Budayr, 1966; Tipper, 1985; for reviews, see Fox, 1995; May, Kane, & Hasher, 1995). The negative priming effect has been examined in great detail because it provides a window into the processes involved in selective attention. Initially, the critical process involved in negative priming was assumed to be inhibitory in nature (Greenwald, 1972; Neill, 1977). More recent investigations have suggested a memory retrieval process (Neill, 1997; Neill & Valdes, 1992; Neill, Valdes, Terry, & Gorfein, 1992) or a process that combines both attention and memory-based processes (Kane, May, Hasher, Rahhal, & Stoltzfus, 1997; Milliken, Joordens, Merikle, & Seiffert, 1998). For the purposes of this paper, we remain atheoretical as to what specific process is critical to the negative priming effect. We do assume, however, that the processes involved in negative priming are implicated in selective attention more generally. We assume that negative priming is an index of selective attention, and therefore, if we can demonstrate that negative priming is sensitive to certain variables, we will be able to conclude that selective attention is sensitive to those variables.

Two main hypotheses were tested in the present experiments. The first was that the negative priming effect is sensitive to both a verbal and a nonverbal cognitive load. The second was that individual differences in working memory capacity correspond to individual differences in the negative priming effect. This introduction will provide insight into the motivation for these two hypotheses.

Our previous work has already demonstrated that the negative priming effect is sensitive to cognitive load (Engle, Conway, Tuholski, & Shisler, 1995). In Engle et al. (1995), subjects performed a letter naming task in which their primary task was to name aloud a letter of a given color, while ignoring an overlapping letter of another color. Many researchers have shown that if the to-be-ignored distractor letter on one display (prime display) becomes the to-be-named target letter on a subsequent display (probe display), naming time is slowed on the probe. This increase in naming time is the negative priming effect. In Engle et al. (1995), the subjects' secondary task was to remember unrelated words, presented after each probe trial. Thus, for the initial prime–probe pair, there was no cognitive load, and for each subsequent prime–probe pair, the load increased. Engle et al. (1995) found that the negative priming effect diminished as cognitive load increased. Operating under the assumption that negative priming reflects an inhibitory process, Engle et al. (1995) concluded that the process of inhibition is effortful and resource demanding, and therefore that when a cognitive load is introduced, inhibition is no longer possible, and the negative priming ef-

---

We thank Michael Kane, G. A. Radvansky, Geoffrey Loftus, and Jonathan Schooler for their helpful comments on an earlier version of this manuscript. Please address correspondence to A. R. A. Conway, University of Illinois, Department of Psychology (M/C 285), 1007 West Harrison Street, Chicago, IL 60607 (e-mail: aconway@uic. edu).

fect is no longer revealed. This conclusion is consistent with other evidence suggesting that inhibition is resource demanding (Conway & Engle, 1994; Nakagawa, 1991; Roberts, Hager, & Heron, 1994). However, as mentioned above, it is not clear that the critical process involved in negative priming is inhibition. Regardless, the Engle et al. (1995) experiment demonstrates that whatever mechanism is responsible for the negative priming effect, it is sensitive to cognitive load.

Engle et al. (1995) argued that the process critical to negative priming and to selective attention more generally is domain free, relying on general "attentional resources." However, a potential criticism of the Engle et al. (1995) experiment is that both the primary task (letter naming) and the secondary task (remembering words) required the manipulation of verbal information. It is possible, then, that the diminished negative priming observed by Engle et al. (1995) was due to a domain-specific conflict, not a competition for domain-free resources. Therefore, one goal in the present experiments was to replicate Engle et al.'s (1995) finding that negative priming was sensitive to a verbal work-load and then generalize the finding to a situation in which a nonverbal work-load was employed. If negative priming is diminished under both a verbal and a nonverbal load, the conclusion that the processes involved in negative priming rely on a general resource pool would be supported.

Our second hypothesis was that individual differences in working memory capacity would correspond to individual differences in negative priming. To date, differences in negative priming have only been reported when patient groups (i.e., schizophrenics, Alzheimer's patients) have been compared with control groups or when groups of subjects at different stages of development have been compared (i.e., children and young adults or young adults and elderly adults) (i.e., Beech, Powell, McWilliam, & Claridge, 1989; Hasher, Stoltzfus, Zacks, & Rypma, 1991; Sullivan, Faust, & Balota, 1995; Tipper, Bourque, Anderson, & Brehaut, 1989). The typical finding is that groups that fail to reveal the negative priming effect (schizophrenics, Alzheimer's patients, children, the elderly) also have a more general deficit in blocking out interfering or distracting information (Cohen & Servan-Schreiber, 1992; Dempster, 1992; Hasher & Zacks, 1988; Simone & Baylis, 1997).

Research from our lab on individual differences in working memory capacity has demonstrated that high and low working memory capacity individuals differ in their ability to handle interference (Conway & Engle, 1994; Kane & Engle, 1997; Rosen & Engle, 1997; Tuholski, 1994). For example, Conway and Engle (1994) reported a series of experiments which suggest that individual differences in working memory capacity correspond to differences in the ability to handle irrelevant information. In two experiments, subjects memorized sets of words and then performed a speeded recognition task, in which their memory of the sets was tested. In one experiment, the sets were constructed so that each set item was a member of two different sets. For example, if the word *dog* was a member of Set 6, it might also be a member of Set 4. In another experiment, each set item was a member of only one set. Conway and Engle found that when there was no overlap in set membership, high- and low-span subjects had identical reaction time slopes, indicating no difference in retrieval rate. However, when there was an overlap in set membership, low-span subjects showed a significantly steeper slope than did high-span subjects. Thus, the low-span subjects were adversely affected by the interference manipulation, but the high-span subjects were not.

Therefore, it appears that high-span subjects are able to efficiently handle interfering information, whereas low-span subjects are not. On the basis of this and of the finding that experimental groups that have difficulty under conditions of interference also fail to demonstrate negative priming, we predicted that high-span subjects would demonstrate the negative priming effect but that low-span subjects would not.

To recap, in the present experiments we tested two main hypotheses. The first was that the negative priming effect would be sensitive to both a verbal and a nonverbal cognitive load. The second was that individual differences in working memory capacity would reveal themselves in the negative priming effect. Two letter naming experiments are reported, which differed only in the concurrent secondary task that subjects performed (verbal or nonverbal). In the first experiment, subjects performed the letter naming task while remembering words. In the second experiment, subjects performed the letter naming task while remembering polygons. To preview the results, both verbal and nonverbal secondary tasks effectively eliminated the negative priming effect. Also, in both experiments, high-span subjects showed reliable negative priming, but only under no-load conditions. Regardless of load condition, low-span subjects did not show reliable negative priming in either experiment.

Subject Screening

Subjects were screened for working memory capacity on the basis of their performance on an operation–word span task similar to that used by Conway and Engle (1994). The operation–word span task is one of the most popular measures of working memory capacity, and in a factor analytic study (Engle, Tuholski, Laughlin, & Conway, 1999), the operation–word span measure loaded on the same factor as other well-established measures of working memory capacity, such as reading span (Daneman & Carpenter, 1980) and counting span (Case, Kurland, & Goldberg, 1982).

Operation–Word Span Task

The subjects were instructed that the task would require them to solve simple math problems while they tried to remember words. The task began with the experimenter pressing the space bar on a keyboard, which caused the presentation of a mathematical operation and a word— for example, (6/2) + 2 = 5 ? DOG. The subject's task was to read the operation aloud and to say "yes" or "no" to indicate whether the given answer was correct or incorrect (the given answer was correct approximately half the time). After stating "yes" or "no," the subject read the word aloud, at which point the experimenter pressed the space bar to present the next operation–word pair. This process continued until the subject saw the word RECALL appear on the screen, at which point the subject wrote down all the words presented in the previous series. The number of operation–word pairs per series varied from two to six (three series of each length were performed, and the order of presentation was random, so that the subject could not predict series length).

The dependent measure, or *span score*, was the sum of words correctly recalled from series that were recalled perfectly (all words in their correct order with no intrusions). For example, if a subject recalled all three of the length two series and one of the length three series, the span score would be 9 (2 + 2 + 2 + 3). This span score, originally reported by Turner and Engle (1989), consistently correlates with VSAT (Cantor & Engle, 1993; Engle, Cantor, & Carullo, 1992; LaPointe & Engle, 1990) and accounts for the same variance in the VSAT as do scores on the reading span task (Turner & Engle, 1989).

If accuracy on the mathematical operations was below 85%, the subject did not participate in either of the following experiments.[1] Subjects who scored 19 or higher were classified as high span, and those who scored 10 or lower were classified as low span. These cutoffs reflect the upper and lower quartiles of our subject pool (approximately 400 subjects) during the time when these experiments were conducted.

EXPERIMENT 1

Method

Subjects. Ninety-five undergraduate students at the University of South Carolina participated for class credit. Fourteen subjects were dropped for various reasons, such as computer error, failure to participate in the operation–word span task, awareness of the relationship between prime and probe displays, or experimenter error. One subject was dropped because of abnormally long response times (6,000 msec). Of the 80 total subjects, 23 were classified as high span and 26 were classified as low span.

Design. Each subject performed 320 trials (eight blocks of 40 trials each). Each trial consisted of a prime display followed by a probe display. A typical display consisted of a red letter and a green letter. The subject's task was to name the red letter as quickly and accurately as possible. Trials were constructed in groups of 5. After each trial, a word was presented for later recognition. After the 5th and last trial of the group, a test word was presented and the subject had to indicate, by pressing a key, whether the test word matched one of the four previously presented words. Thus, within a group of 5 trials, the memory load started at zero words for the 1st trial and incremented to four words for the 5th trial.

Two independent variables were manipulated: load and trial type. *Load*, or the number of words presented for later recognition, varied from zero to four. There were four types of trials: *control*, *filler*, *distractor–target*, and *no selection*. On control and filler trials, the letters on the prime display were unrelated to the letters on the probe display. On distractor–target trials, the to-be-named (red) letter on the probe display was the same as the to-be-ignored (green) letter on the prime display. On no-selection trials, a red letter was presented alone on the prime display, and both the red and green letters on the probe display were unrelated to the prime letter.

The negative priming effect is observed by comparing naming time on control trials with that on distractor–target probe trials. Because our main hypotheses are concerned with negative priming effects, our main analyses will focus on naming time to probe displays and will include distractor–target and control trials only. The purpose of including no selection trials was to allow a measure of interference caused by the distractor on the prime display. The difference between naming time for no-selection prime displays and control prime displays provides an estimate of distractor interference.

The purpose of the filler trials was to create equal numbers of trials for each trial type while maintaining that 25% of the trials be distractor–target. We wanted to maintain a low percentage of distractor–target trials because when the percentage of such trials is high, subjects tend to become aware of the relationship between prime and probe and do not exhibit the negative priming effect (May et al., 1995).

Procedure. A complete set of trials proceeded as follows (see Figure 1). A set of four asterisks was presented for 750 msec, followed by the prime display for 150 msec. Following the subject's response to the prime display, another set of asterisks was presented for 750 msec, followed by the probe display for 150 msec. This pair of prime and probe displays was assumed to be under load 0 because

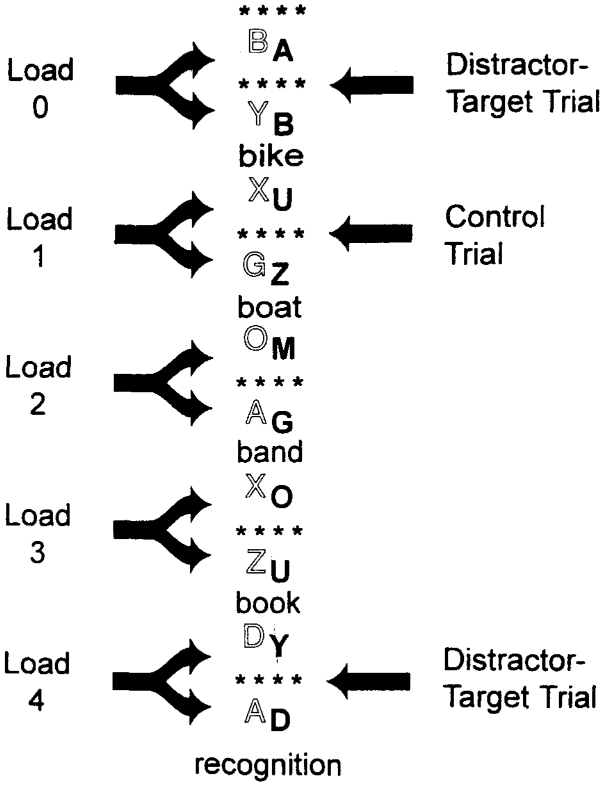

Figure 1. Example of a complete set of trials. The dark letters represent red letters, and the light letters represent green letters.

the subject had not yet been presented with an item for later recognition. After the probe display, a word appeared for 750 msec in the location of the previous asterisks. The next trial (prime and probe) was considered to be under load 1 because one to-be-remembered word had been presented. This process continued until after the fifth probe display, at which time one of eight words from a fixed pool (*bike*, *back*, *boot*, *book*, *bite*, *boat*, *band*, *bone*) appeared on the screen. The subject's task was to decide whether the test word matched one of the four previously presented words. The subject pressed the "1" key to indicate a match or the "3" key to indicate a mismatch.

Trials were randomized, with two constraints. First, there were equal numbers of each trial type within each block. Second, for all prime displays, the red letter was different from the red and green letters on the previous probe display.

The experiment was run on a Dell computer with a VGA monitor, using Micro-Experimental Laboratory (MEL) (Schneider, 1988). Subjects spoke into a hand-held microphone connected to a MEL response box (Version 4.0). Latency to name the letter was measured from the presentation of the letter until the oral response activated a speech trigger. Naming latency, as well as recognition accuracy, was recorded by the computer while the experimenter recorded naming accuracy.

Results

Three dependent measures are reported here: naming latency, naming error rate, and recognition accuracy. Analyses of these three measures are reported for all subjects. Subsequent analyses are also reported, in which we compared the naming latency of high- and low-span subjects.

Our main hypotheses concerned either the presence or the absence of negative priming effects. A significant negative priming effect is illustrated by significantly longer naming times to distractor–target probes than to control probes. Thus, in our analyses we relied on planned comparisons involving direct comparison of a distractor–target condition with its appropriate control. Specifically, we conducted planned comparisons to test whether negative priming occurred (1) under no load conditions, (2) under load conditions, (3) for high-span subjects, and (4) for low-span subjects.

Naming latency. The means of subjects' median naming times are shown in Figure 2. A 2 × 5 repeated measures analysis of variance (ANOVA) was conducted, with trial type (distractor–target, control) and memory load (0, 1, 2, 3, 4) as the variables. There was a main effect of trial type [$F(4,316) = 17.91$, $MS_e = 643$, $p < .01$], such that responses to distractor–target trials were slower than responses to control trials, which is the negative priming effect. There was also a main effect of load [$F(1,79) = 12.64$, $MS_e = 433$, $p < .01$]. Tukey's HSD test indicated that responses were faster at load 0 than at any other level of load, and responses at the other levels of load did not differ from each other. Load and trial type did not interact ($F < 1$). However, planned comparisons revealed a small but reliable negative priming effect of 9 msec at load 0 [$F(1,316) = 8.53$, $MS_e = 388$, $p < .05$]. Negative priming was not observed under any other load condition (for all planned comparisons, $p > .10$).

Naming errors. Mean error rate is also shown in Figure 2. A 5 (memory load) × 2 (trial type) ANOVA indicated a main effect of trial type [$F(1,79) = 5.81$, $MS_e = .0012$, $p < .05$], such that naming errors were less common for control trials (2.12%) than for distractor–target trials (2.71%). Neither the main effect of load nor the interaction between load and trial type was significant (for both, $p > .10$).

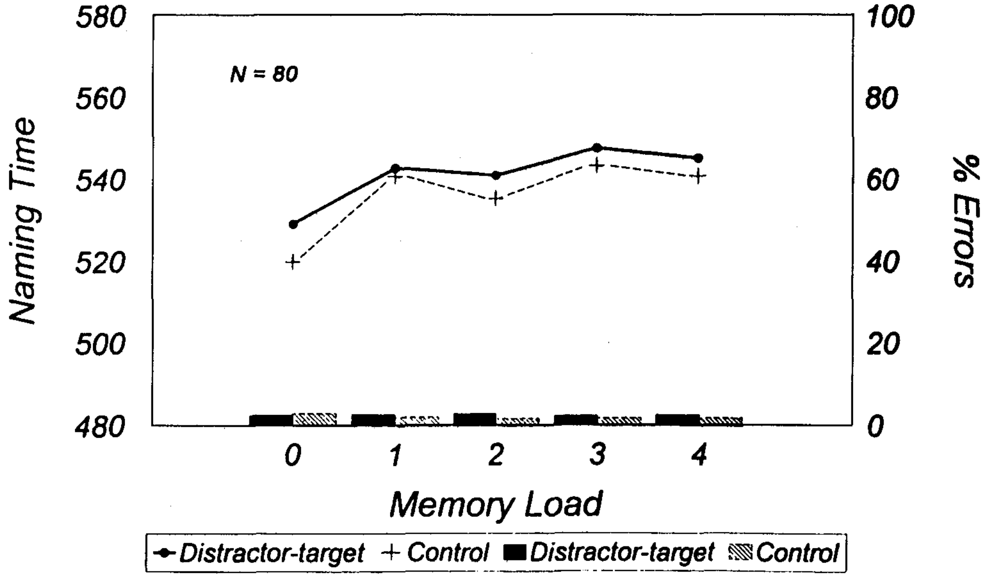

Figure 2. Naming time (in milliseconds) and error percentage for distractor–target and control trials in Experiment 1.

Recognition accuracy. To validate the difficulty of the secondary task, we analyzed recognition accuracy for the words by position of the secondary stimuli. Position 1 is equal to a level of load 1, Position 2 is equal to a level of load 2, etc. On half the trials, the test word was one that was not presented (a mismatch). Because there was no "position" for these trials, they were labeled mismatches. A one-way ANOVA was performed with position as the independent variable. This analysis indicated that recognition accuracy increased as the position of the test word became closer to the test probe [$F(4,320) = 51.94$, $MS_e = .279$, $p < .01$]. Tukey's HSD test indicated that accuracy was worst for mismatches (see Table 1). For matches, accuracy was worst at Positions 1 and 2, significantly better at Position 3, and best at Position 4.

Individual differences in negative priming. To test whether high- and low-span subjects showed different negative priming effects, we conducted a 2 × 5 × 2 mixed ANOVA on naming latency, with span group (high, low) as the between-subjects variable. The naming latencies for high- and low-span subjects are presented in Figure 3. As with the previous analysis, naming latency at load 0 was faster than at all other levels of load [$F(4,188) = 10$, $MS_e = 616$, $p < .01$]. The negative priming effect was marginally significant [$F(1,47) = 3.27$, $MS_e = 431$, $p = .077$]. The main effect of span group was not significant ($F < 1$), nor were any of the interactions (for all, $p > .10$). However, planned comparisons revealed that high-span subjects demonstrated reliable negative priming of 14 msec at load 0 [$F(4,188) = 23.9$, $MS_e = 188$, $p < .05$], but not at any other level of load (for all, $p > .10$). Low-span subjects did not demonstrate reliable negative priming under any level of load (for all, $p > .10$).

Discussion

Experiment 1 provided a replication of Engle et al. (1995) in demonstrating that the negative priming effect was diminished when the subject had to maintain a secondary memory load. Again, this suggested that the process involved in negative priming, be it inhibition, memory retrieval, or a combination of both, was resource dependent. The question remained whether the resources were specific to verbal information or whether the resources were domain free. We addressed this question in the next experiment. If negative priming, as measured in the letter naming task, is affected by a *nonverbal* memory load in the same manner as it is by a verbal memory load, one can conclude that the process involved in negative priming is domain-free. In contrast, if negative priming remains under a nonverbal memory load, this would suggest that the resources devoted to negative priming are tied to the modality of the stimuli used.

Table 1
Percent Accuracy of Recognition in the Secondary Task for Experiments 1 and 2

Position	Experiment 1	Experiment 2
Mismatch	57	61
1	65	70
2	71	72
3	71	79
4	83	92

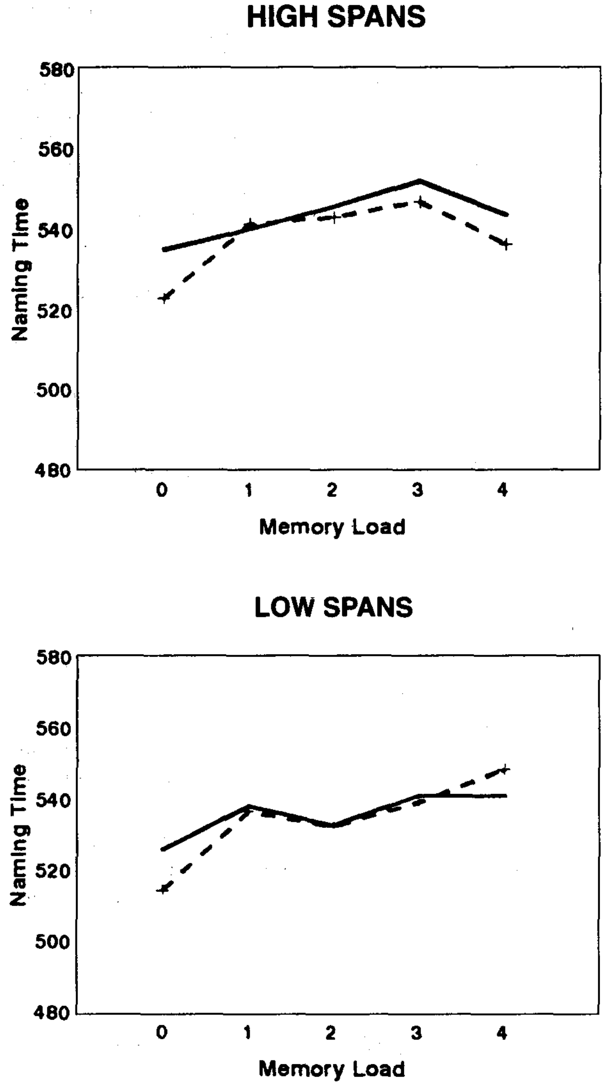

Figure 3. Naming time (in milliseconds) for high- and low-span subjects in Experiment 1. Solid lines, distractor–target; broken lines, control.

Our prediction with regard to individual differences was supported. That is, high-span, but not low-span subjects revealed significant negative priming. This finding supported our hypothesis that subjects able to efficiently handle task interference would demonstrate the negative priming effect, whereas subjects inefficient at dealing with task interference would not show the negative priming effect. The negative priming effects of high and low working memory capacity individuals were also compared in Experiment 2.

EXPERIMENT 2

Method

Subjects. Seventy-seven undergraduate students from the University of South Carolina participated for class credit. These subjects were recruited from our subject pool on the basis of their span scores. Two of the subjects were dropped because of computer error. Of the 75 remaining subjects, 15 were classified as high span and 21 were classified as low span.

Design and Procedure. The design and procedures for Experiment 2 were the same as in Experiment 1. The only difference between the experiments was the nature of the to-be-remembered stimuli. Instead of words, polygons (see Figure 4) were used as stimuli.

Results

Naming latency. The means of the subjects' median naming times are shown in Figure 5. These data were entered into a 2 × 5 repeated measures ANOVA with trial type (distractor–target and control) and memory load (0, 1, 2, 3, 4) as the variables. There was a negative priming effect, reflected by the main effect of trial type [$F(1,74) = 19.00$, $MS_e = 354$, $p < .01$]. There was also a main effect of memory load [$F(4,296) = 27.70$, $MS_e = 560$, $p < .01$]. Tukey's HSD test indicated that response times at load 0 were significantly faster than response times at loads 1–4, which did not differ from each other. The interaction between trial type and memory load failed to reach significance [$F(4,296) = 1.21$, $MS_e = 427$, $p > .10$]. Despite the lack of interaction between trial type and memory load, planned comparisons revealed significant negative priming (12 msec) at load 0 [$F(1,296) = 12.63$, $MS_e = 427$, $p < .05$]. The negative priming effect was not significant at any other level of load, (for all planned comparisons, $p > .10$).

Naming errors. Letter naming error rates are also reported in Figure 5. As with the latency data, a 2 × 5 repeated measures ANOVA was conducted, with trial type and memory load as the variables. There was a main effect of trial type [$F(1,74) = 4.39$, $MS_e = 0.0013$, $p < .05$], such that subjects made more errors on distractor–target than on control trials. The main effect of memory load was not significant, nor was the interaction between trial type and load (for both, $p > .10$).

Recognition accuracy. Mean accuracy is reported in Table 1. A one-way repeated measures ANOVA indicated a significant effect of position [$F(4,320) = 51.94$, $MS_e = .439$, $p < .01$]. Tukey's HSD test indicated that accuracy was worst for mismatches. For matches, accuracy was worst for Positions 1 and 2, significantly better for Position 3, and best for Position 4.

Individual differences in negative priming. To test whether high- and low-span subjects showed different negative priming effects, a 2 × 5 × 2 mixed ANOVA was conducted, with span group (high, low) as the between-subjects variable. Adding span as a variable did not affect the main effects of trial type or load (both still significant at the .05 level). None of the interactions between the variables were significant (for all, $p > .10$).

The data for high- and low-span subjects are shown in Figure 6. Planned comparisons confirmed a reliable negative priming effect of 16 msec for high-span subjects at load 0 [$F(1,136) = 18.29$, $MS_e = 524$, $p < .05$], but high-span subjects did not show reliable negative priming under any other conditions of load (for all, $p > .10$). Low-span subjects did not show reliable negative priming at any load ($p > .10$ for all), even at a load of 0.

Discussion

The results of Experiment 2 parallel those from Experiment 1. Negative priming was found only when the memory load was zero. At all levels of load, the negative priming effect failed to reach significance. This result, taken together with those of Engle et al. (1995) and in Experi-

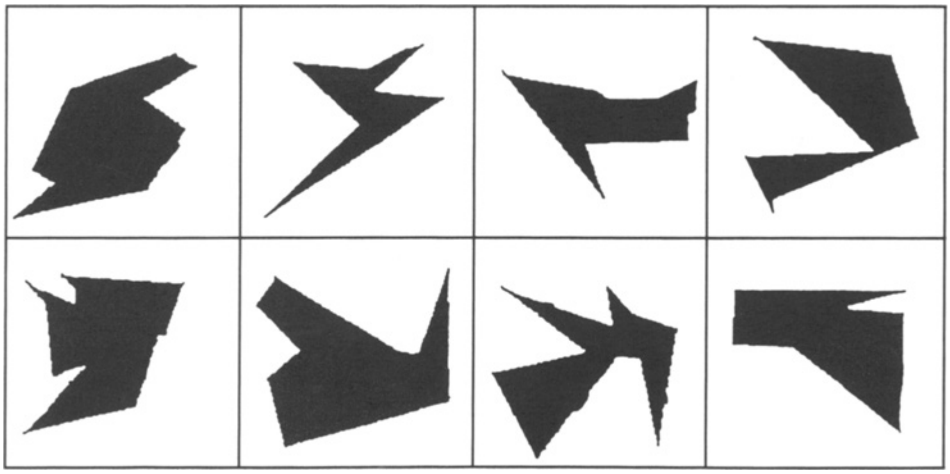

Figure 4. Polygons used as stimuli for memory load in Experiment 2.

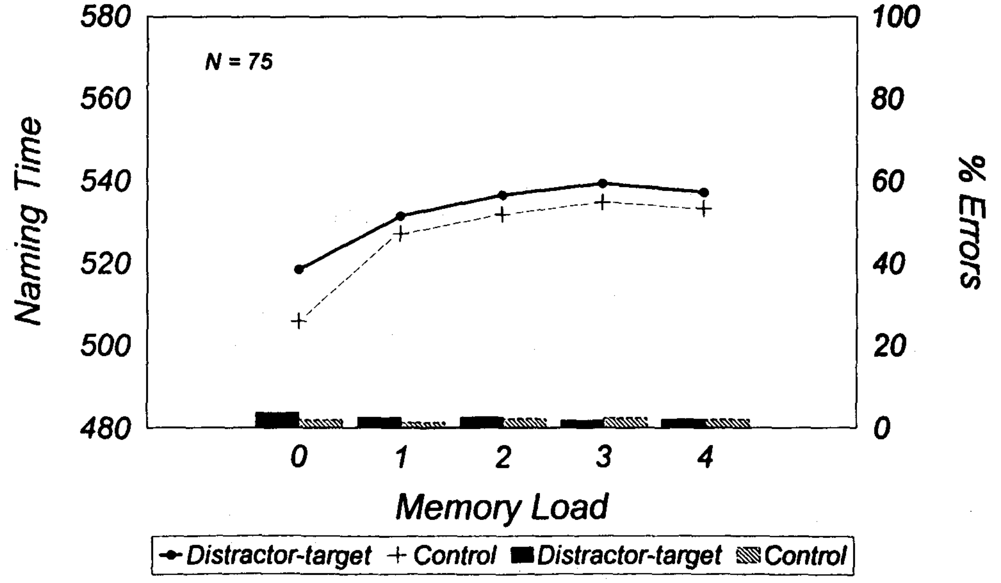

Figure 5. Naming time (in milliseconds) and error percentage for distractor–target and control trials in Experiment 2.

ment 1, suggests that the process that contributes to the negative priming effect is a resource-dependent process and that the resource pool is domain free.

As in Experiment 1, individual differences in the negative priming effect were observed. Again, high-span subjects revealed significant negative priming whereas low-span subjects did not, supporting the contention that working memory capacity corresponds to the ability to handle task interference efficiently.

GENERAL DISCUSSION

Our main hypotheses were as follows: If the processes that contribute to the negative priming effect require domain-free resources, negative priming should be affected by both a verbal and a nonverbal memory load. Furthermore, subjects measured to have high and low working memory capacity should differ in the amount of resources available to them, and as such, should show a different pattern of negative priming effects. Both hypotheses were supported by our results. First, in both experiments, we found significant negative priming only at load 0. Second, high-span subjects revealed reliable negative priming at load 0 in both experiments, whereas low-span subjects did not show negative priming in either experiment. Taken together, these results support the notion that negative priming requires general resources and that individual differences in the amount of resources available will result in individual differences in the negative priming effect.

Our manipulation of secondary load was apparently successful, as is indicated by the main effect of load in the naming time data and by the main effect of load in the recognition accuracy data. These results suggest that as a word or a polygon was presented for later recognition, the task became more difficult, resulting in an increase in the time required to name the letters and in poorer recognition of words or polygons.

The present experiments suggest two main conclusions. First, the processes involved in selective attention are sensitive to both a verbal and a nonverbal cognitive load. Second, individual differences in working memory capacity correspond to selective attention ability.

Although these are important conclusions, they beg at least two critical questions. First, what is (are) the specific process(es) involved in negative priming and why are they sensitive to cognitive load? The present results are not consistent with a strict episodic retrieval explanation of negative priming (cf. Neill, 1997), because the retrieval of prior episodic traces, which contributes to the negative priming effect, is assumed to be automatic (Logan, 1988). It is not clear why the introduction of a cognitive load should interrupt an automatic retrieval process.

The results are more consistent with an explanation of negative priming that relies on the inclusion of an effortful process, be it inhibition, or a dual process, such as those proposed by Kane et al. (1997) and Milliken et al. (1998). If the dual process models are correct, an interesting direction for future research would be to pinpoint the part of the process that is sensitive to load. That is, is it possible to identify a part of the process that operates efficiently under load, while isolating another part of the process that breaks down under load?

The second question that remains is a chicken–egg dilemma. Does working memory capacity drive the ability to handle distraction, or does the ability to handle distraction

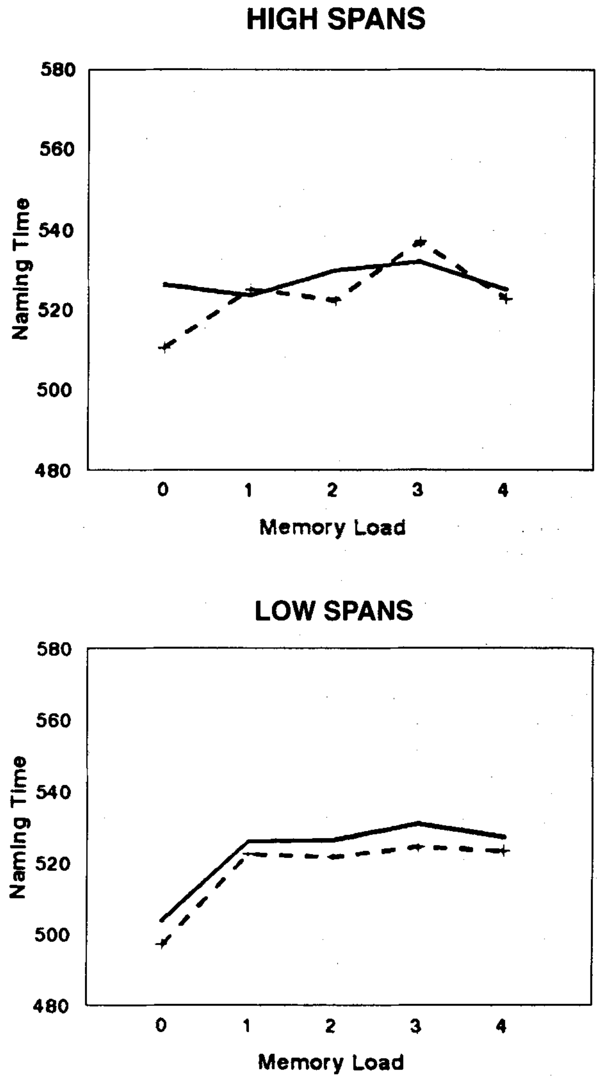

Figure 6. Naming time (in milliseconds) for high- and low-span subjects in Experiment 2. Solid lines, distractor–target; broken lines, control.

drive working memory capacity? We have argued elsewhere (Conway & Engle, 1994; Engle et al., 1995) that inhibition is the mechanism responsible for handling distraction and that inhibition is resource dependent. Thus, individuals with high working memory capacity will be more likely to inhibit distracting information. According to that framework, working memory capacity drives the ability to handle interference.

It is still plausible, however, that high-span subjects are classified as high span because they have an efficient inhibitory mechanism that successfully contributes to performance on the operation span task. These individuals may use their ability to handle interference while participating in the operation span task, and this ability may contribute to their above average performance. If so, it would not be surprising to find that these subjects are the ones who demonstrate the negative priming effect. According to this framework, an efficient inhibitory mechanism drives working memory capacity (Hasher & Zacks, 1988).

It is important to note that these conflicting accounts provide different explanations of the effect of load on negative priming. According to the hypothesis that working memory capacity drives the ability to handle distraction, the momentary resources available to the system become diminished as load increases; therefore inhibition is no longer possible, and the negative priming effect is no longer observed. According to the hypothesis that an inhibitory mechanism drives working memory capacity, the inhibitory mechanism must be sensitive to both a verbal and a nonverbal load, so that it no longer operates when a load is introduced. Thus, even under this framework, the inhibitory mechanism is sensitive to load and is domain free. In essence, this approach would have to claim that whatever mechanisms or processes are responsible for inhibition are also sensitive to domain-free interference. In fact, such effects are possible in a computational approach to negative priming that does not resort to a resource notion (Houghton & Tipper, 1994).

Future research will need to establish more clearly the relationship between working memory capacity and the ability to handle interference. The present experiments and our previous work (Conway & Engle, 1994; Kane & Engle, 1997; Rosen & Engle, 1997; Tuholski, 1994) clearly demonstrate that the two are inextricably related, but the exact nature of the relationship is still not well specified.

REFERENCES

Beech, A., Powell, T., McWilliam, J., & Claridge, G. (1989). Evidence of reduced "cognitive inhibition" in schizophrenia. *British Journal of Psychology*, **28**, 110-116.

Cantor, J., & Engle, R. W. (1993). Working memory capacity as long-term memory activation: An individual differences approach. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **5**, 1101-1114.

Case, R., Kurland, M. D., & Goldberg, J. (1982). Operational efficiency and the growth of short-term memory span. *Journal of Experimental Child Psychology*, **33**, 386-404.

Cohen, J. D., & Servan-Schreiber, D. (1992). Context, cortex, and dopamine: A connectionist approach to behavior and biology in schizophrenia. *Psychological Review*, **99**, 45-77.

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.

Dalrymple-Alford, E. C., & Budayr, B. (1966). Examination of some aspects of the Stroop colour–word test. *Perceptual & Motor Skills*, **23**, 1211-1214.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning & Verbal Behavior*, **19**, 450-466.

Dempster, F. N. (1992). The rise and fall of the inhibitory mechanism: Toward a unified theory of cognitive development and aging. *Developmental Review*, **12**, 45-75.

Engle, R. W., Cantor, J., & Carullo, J. J. (1992). Individual differences in working memory and comprehension: A test of four hypotheses. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **18**, 972-992.

Engle, R. W., Conway, A. R. A., Tuholski, S. W., & Shisler, R. J. (1995). A resource account of inhibition. *Psychological Science*, **6**, 122-125.

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. A.

(1999). Working memory, short-term memory, and general fluid intelligence: A latent variable approach. *Journal of Experimental Psychology: General*, **128**, 309-331.

Fox, E. (1995). Negative priming from ignored distractors in visual selection: A review. *Psychonomic Bulletin & Review*, **2**, 145-173.

Greenwald, A. G. (1972). Evidence of both 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, & 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). San Diego, CA: Academic Press.

Houghton, G., & Tipper, S. P. (1994). A model of inhibitory mechanisms in selective attention. In D. Dagenbach & T. H. Carr (Eds.), *Inhibitory processes in attention, memory, and language* (pp. 53-112). San Diego: Academic Press.

Kane, M. J., & Engle, R. W. (1997). *Working memory, divided attention and interference*. Paper presented at the annual meeting of the Midwestern Psychological Association, Chicago.

Kane, M. J., May, C. P., Hasher, L., Rahhal, T., & Stoltzfus, E. R. (1997). Dual mechanisms of negative priming. *Journal of Experimental Psychology: Human Perception & Performance*, **23**, 632-650.

LaPointe, L. B., & Engle, R. W. (1990). Simple and complex word spans as measures of working memory capacity. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **16**, 1118-1133.

Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological Review*, **95**, 492-527.

May, C. P., Kane, M. J., & Hasher, L. (1995). Determinants of negative priming. *Psychological Bulletin*, **188**, 35-54.

Milliken, B., Joordens, S., Merikle, P., & Seiffert, A. (1998). Selective attention: A re-evaluation of the implications of negative priming. *Psychological Review*, **105**, 203-229.

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 selective attention. *Journal of Experimental Psychology: Human Perception & Performance*, **3**, 444-450.

Neill, W. T. (1997). Episodic retrieval in negative priming and repetition priming. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **23**, 1291-1305.

Neill, W. T., & Valdes, L. A. (1992). Persistence of negative priming: Steady state or decay? *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **18**, 565-576.

Neill, W. T., Valdes, L. A., Terry, K. M., & Gorfein, D. S. (1992). Persistence of negative priming: II. Evidence for episodic trace retrieval. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **18**, 993-1000.

Roberts, R. J., Hager, L. D., & Heron, C. (1994). Prefrontal cognitive processes: Working memory and inhibition in the antisaccade task. *Journal of Experimental Psychology: General*, **123**, 374-393.

Rosen, V. M., & Engle, R. W. (1997). The role of working memory capacity in retrieval. *Journal of Experimental Psychology: General*, **126**, 211-227.

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

Simone, P. M., & Baylis, G. C. (1997). Selective attention in a reaching task: Effect of normal aging and Alzheimer's disease. *Journal of Experimental Psychology: Human Perception & Performance*, **23**, 595-608.

Sullivan, M. P., Faust, M. E., & Balota, D. A. (1995). Identity negative priming in older adults and individuals with dementia of the Alzheimer type. *Neuropsychology*, **9**, 537-555.

Tipper, S. P. (1985). The negative priming effect: Inhibitory priming by ignored objects. *Quarterly Journal of Experimental Psychology*, **37A**, 571-590.

Tipper, S. P., Bourque, T. A., Anderson, S. H., & Brehaut, J. C. (1989). Mechanisms of attention: A developmental study. *Journal of Experimental Child Psychology*, **48**, 353-378.

Tuholski, S. W. (1994). *Individual differences in the fan effect: The effect of interference*. Unpublished master's thesis, University of South Carolina, Columbia.

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent? *Journal of Memory & Language*, **28**, 127-154.

NOTE

1. Less than 5% of subjects tested in the operation span task performed below this level. Again, any subject who did not perform to this level of accuracy was not asked to participate in either experiment.

(Manuscript received February 12, 1998;
revision accepted for publication January 21, 1999.)