Journal of Experimental Psychology:
Learning, Memory, and Cognition
2007, Vol. 33, No. 4, 645–662

0278-7393/07/$12.00 DOI: 10.1037/0278-7393.33.4.645

Attentional Control and the Relatedness Proportion Effect in Semantic Priming

Keith A. Hutchison
Montana State University

In 2 experiments, participants completed both an attentional control battery (OSPAN, antisaccade, and Stroop tasks) and a modified semantic priming task. The priming task measured relatedness proportion (RP) effects within subjects, with the color of the prime indicating the probability that the to-be-named target would be related. In Experiment 2, participants were cued before each trial with the probability of a related target. Stimulus onset asynchronies traditionally thought to tap automatic processing (267 ms) versus controlled processing (1,240 ms) were used. Across experiments, principal component analysis on the battery revealed a general attentional control component. Moreover, the RP effect increased linearly with attentional control in both experiments. It is concluded that RP effects produced in this paradigm depend purely upon the effortful process of expectancy generation, which renders them sensitive to individual differences in attentional control.

Keywords: semantic priming, relatedness proportion, attention, working memory

In the 1970s, researchers established guidelines for determining whether behaviors are performed automatically or require conscious control (Hasher & Zacks, 1979; Posner & Snyder, 1975a; Shiffrin & Schneider, 1977). For example, Posner and Snyder's (1975a) criteria defined an automatic process as one that (a) is fast acting; (b) occurs without intention; (c) is not open to conscious awareness or introspection; and (d) consumes few, if any, conscious resources. Controlled processes are ones that, by default, do not meet these criteria.

Posner and Snyder's (1975a) criteria were derived partly from their own work examining reaction time (RT) performance in a stimulus–classification task. Posner and Snyder (1975b) found that either letter-matching or animal-classification performance on a target array was facilitated if an initial cue stimulus, called the *prime*, matched the items in the target array. They examined the contribution of conscious attention to performance on this task by manipulating the proportion of trials in which the prime cue appeared in the target array (prime validity). Under high relatedness proportions, the prime would allow participants to selectively focus their attention on expected items. Posner and Snyder found that increasing the proportion of valid prime trials increased facilitation for such trials but also produced a cost on invalid trials, relative to a neutral prime. Critically, this cost only appeared at longer stimulus onset asynchronies (SOAs; 300 and 500 ms), between the prime and target array, but not at shorter SOAs (< 300 ms). Posner and Snyder concluded that both automatic and consciously controlled processes could produce facilitation but that the consciously controlled process alone produced the cost on invalid trials. Moreover, this consciously controlled process occurred only when (a) the prime validly predicted the upcoming targets and (b) the SOA was long enough for participants to direct attention to the expected items.

Considerable support for Posner and Snyder's (1975a) two-process model has been provided by researchers using the semantic-priming paradigm. In this paradigm, a prime word is presented that is semantically related (e.g., *cat*) or unrelated (e.g., *wall*) to a later target word (e.g., *dog*). The semantic-priming effect refers to the ubiquitous finding that people are faster to provide either a speeded naming or a lexical (word or nonword) decision task (LDT) response to a target following a related prime than following an unrelated prime. In general, results from this paradigm have lent support to both automatic and consciously controlled semantic-priming mechanisms (see Neely, 1991, for a review). The most common explanation for the automatic mechanism is a spreading-activation process, in which the prime item activates its semantic representation and this activation spreads to associatively related concepts, speeding their later identification (Meyer & Schvaneveldt, 1971; but see Stolz & Besner, 1996, 1998, for arguments against the automaticity of semantic activation). In contrast, an expectancy process has often been invoked to explain consciously controlled semantic priming. This process involves the generation and maintenance of possible targets during the SOA period, between the prime and target (Becker, 1980; Neely, 1977). For example, according to Becker's verification model (Becker, 1980), the recognition of a prime word allows the participant to generate a set of words semantically related to the prime. Once the target word appears, it activates a second set of visually similar words on the basis of visual-feature extraction and word-detector processes. This visually similar set could be compared one by one with the visual trace of the target in sensory memory, until the correct word is identified. However, because the

---

These data were presented at the November 2005 meeting of the Psychonomic Society in Toronto, Ontario, Canada. I thank Jesse Bengson, Frank Bosco, Dan Colado, Brian Haviland, Philip Massine, Alesha Mowrey, Erin Schaus, Jennifer Tuomi, Curt Widhalm, and Zach Shipstead for their assistance in data collection. I also thank Dave Balota, Rick Block, Sachiko Kinoshita, Randi Martin, Jim Neely, and Tram Neill for their helpful suggestions.

Correspondence concerning this article should be addressed to Keith A. Hutchison, Department of Psychology, 304 Traphagen Hall, Montana State University, Bozeman, MT 59717-3440. E-mail: khutch@montana.edu

expectancy set should be generated prior to the visually defined set, it is assumed that participants devote their attention to comparing the target with this set while the visually defined set is still being generated, which allows a match to be found more quickly. Once attention is devoted to the expectancy set, the theory proposes, an exhaustive search ensues before attention can be allocated to the visual set. This theory can therefore explain both the benefits and the costs in RT that emerge when participants engage in a conscious expectancy strategy. Because participants have no basis for generating an expectancy set following a neutral prime (e.g., *xxxx*), response time in this condition primarily reflects the time to generate and search the visually defined set. On other trials, however, participants generate an expectancy set following the prime word, and this set can facilitate or impair response time. On related trials, the target can be found in the expectancy set prior to selection within the visually defined set, which produces facilitation. On unrelated trials, the exhaustive search through the expectancy set delays search through the visual set, which produces inhibition.

Relatedness-Proportion Studies in Semantic Priming

Following Posner and Snyder's (1975b) methodology, researchers have often examined the effect of conscious expectancies on semantic priming by manipulating (a) the proportion of related prime–target pairs in an experiment (the so-called relatedness proportion; RP) and (b) the SOA between the onset of the prime word and the presentation of the probe word (de Groot, 1984; Den Heyer, 1985; Den Heyer, Briand, & Dannenbring, 1983; Hutchison, Neely, & Johnson, 2001; Keefe & Neely, 1990; Neely, 1977; Neely, Keefe, & Ross, 1989; Seidenberg, Waters, Sanders, & Langer, 1984; Stolz & Neely, 1995; Tweedy, Lapinski, & Schvaneveldt, 1977). The general conclusion from such studies is that RP increases priming but only when the SOA is long enough for participants to consciously generate likely targets. However, when the RP is low (making most targets unrelated to the primes) or when the SOA is short (not allowing participants enough time to form expectancies), this conscious strategy is not used, and priming is produced solely by automatic processes. This interpretation of the RP data is so widespread that most researchers now assume that use of a short SOA or a low RP alone ensures them that their priming effects are automatic in nature. However, before one accepts this interpretation, a more thorough investigation of the studies is needed.

The results from 24 experiments with young adults that have manipulated RP in priming tasks are shown in Table 1. In the tasks in these studies, a single response was required at the time of target presentation, which allowed for a precise determination of SOA between prime and target. The experiments listed in the table were classified according to the task (standard LDT, pronunciation, degraded LDT, or double LDT) and were ordered by increasing SOA. In the double-LDT task, participants are presented with primes and targets simultaneously and must indicate whether both are words. In the degraded–LDT task, targets are visually degraded. In pronunciation studies, participants respond by quickly naming the target. Differences in semantic priming across RP (the so-called RP effect) shown in Table 1 were calculated between the highest and lowest RPs used in each study. For example, Den Heyer et al. (1983, Experiment 2) showed a −6-ms RP effect at a 75-ms SOA between their .125–ms RP condition and their .875-ms RP condition (see Table 1).

Examination of studies with the standard-LDT and pronunciation tasks that are listed in Table 1 reveals an increase in RP effects across SOAs, with numerically negative RP effects at less than 100 ms, null RP effects from around 100 to 200 ms, and positive RP effects from 200 ms on. The RP effects are plotted in Figure 1.[1] Examination of Figure 1 reveals a quadratic increase in RP effects across SOA for the lexical decision task ($R^2 = .731$, $p < .001$). Unfortunately, only four RP studies have been conducted with the pronunciation task, and none of those studies have used SOAs between 150 and 450 ms. As a result, it is unknown whether a similar trend exists in this paradigm. As can be seen in Figure 1, the quadratic trend for LDT is due to a linear increase in RP effects across SOA when the SOA is below 400 ms ($R^2 = .436$, $p < .02$), coupled with little-to-no increase in RP effects when the SOA is above 400 ms ($R^2 = .127$, $p > .12$). As an illustrative example, Hutchison et al. (2001) showed a 32-ms increase in RP effects as the SOA increased from 167 to 300 ms but only a 3-ms increase in RP effects as the SOA increased from 300 to 1,200 ms.

It is clear from Figure 1 that strategic priming is possible at 400 ms, as is typically assumed (Neely, 1977). However, the increase in RP effects across SOAs below 400 ms presents a problem for the typical assumption that expectancy is an "all-or-none" strategy that appears only at a critical SOA threshold (for a discussion of this issue, see Hutchison et al., 2001). Clearly, the ability to generate expected targets increases steadily across SOAs well below 400 ms. It is likely that the time course to generate associated targets varies across individuals, across items, and perhaps even across practice with the task. Similarly, although most theorists assume that people do not attempt to generate expectancies at very short SOAs, the pattern of negative RP effects suggests otherwise. It is possible that at such brief SOAs, the generation of possible targets is not complete enough to aid processing of the target and instead creates interference. Of course, in none of the studies was the negative RP effect significant, and so this negative pattern may instead reflect random error.

Lexical Decision Versus Pronunciation

As can be seen in Table 1, RP effects increase across SOA in both LDTs and pronunciation tasks. However, it is difficult to directly compare the pattern of RP effects across tasks, because no studies have manipulated RP in a pronunciation task with an SOA of between 200 and 400 ms. As a result, interpretation of Figure 1 is hampered. In particular, the lack of a conscious threshold for the emergence of expectancy might reflect the fact that all studies with an SOA of between 200 and 400 ms used LDT tasks. The LDT is influenced by an additional semantic-matching strategy, in which participants check back after the target is accessed to see if it is related to the prime in order to bias a "word" or "nonword" response. As discussed by Neely and Keefe (1989), the probability that the target is a nonword, given that it is unrelated to the prime (the so-called nonword ratio), increases along with increases in RP when the probability of a word (or nonword) is equated across

---

[1] This figure excluded the RP effects found by Henik et al. (1994), which asked participants to verbally report the prime after responding to the target. As can be seen in Table 1, this unusual procedure produced RP effects 4–5 times greater than others produced at the same SOA.

Table 1
Semantic Priming Effects From 24 Experiments Manipulating Relatedness Proportion in Healthy Young Adults as a Function of Stimulus Onset Asynchrony Between Prime and Target Words

		Relatedness proportion				
SOA	Experimenter	.01–.25	.26–.50	.51–.75	.76–.99	RP effect
		Standard LDT				
45	Bodner & Masson (2003, Exp. 1a)	14	—	—	24	10
45	Bodner & Masson (2003, Exp. 1b)	10	—	—	24	14
66	Perea & Rosa (2002, Exp. 2)	24	—	—	10	−14
75	Den Heyer et al. (1983, Exp. 2)	36	51	—	30	−6
75	Den Heyer et al. (1983, Exp. 3)	30	35	—	06	−24
83	Perea & Rosa (2002, Exp. 4)	14	—	—	19	5
116	Perea & Rosa (2002, Exp. 2)	43	—	—	52	9
167	Hutchison et al. (2001, Exp. 2)	26	—	31	—	5
200	Stolz & Neely (1995, Exp. 2)[a,b]	34	31	—	—	−3
200	Stolz et al. (2005, Exp. 1)	28	29	38	—	10
240	de Groot (1984)	58	51	74	—	16
240	Henik et al. (1994, Exp. 3)	−8	—	—	118	126
300	Hutchison et al. (2001, Exp. 1)	34	—	71	—	37
350	Stolz et al. (2005, Exp. 1)	34	42	60	—	26
500	Seidenberg et al. (1984, Exp. 2)	41	76	—	—	35
540	de Groot (1984)	66	65	91	—	25
550	Den Heyer (1985)	17	35	—	52	35
700	Brown et al. (2000, Exp. 1)	23	—	—	56	33
800	Stolz & Neely (1995, Exp. 1)[a,b]	45	88	—	—	43
800	Stolz et al. (2005, Exp. 1)	20	40	52	—	32
840	Henik et al. (1994, Exp. 3)	20	—	—	120	100
1,000	Bushell (1996, Exp. 1)	−1	—	—	40	41
1,000	Den Heyer et al. (1983, Exp. 3)	20	34	—	70	50
1,000	Neely et al. (1989, Exp. 1)[c]	—	37	55	67	30
1,000	Neely et al. (1989, Exp. 2)[c,d]	25	36	45	56	31
1,040	de Groot (1984)	59	71	123	—	64
1,200	Hutchison et al. (2001, Exp. 2)	34	—	74	—	40
		Pronunciation				
66	Perea & Rosa (2002, Exp. 3)	13	—	—	2	−11
116	Perea & Rosa (2002, Exp. 3)	15	—	—	13	−2
500	Seidenberg et al. (1984, Exp. 2)	28	30	—	—	2
1,000	Keefe & Neely (1990)[c,e]	—	14	—	32	18
		Degraded target LDT				
200	Stolz & Neely (1995, Exp. 1)[a,f]	46	52	—	—	6
800	Stolz & Neely (1995, Exp. 1)[a,f]	48	120	—	—	72
		Double LDT				
0	Perea & Rosa (2002, Exp. 1)	161	—	—	229	68

Note. A dash indicates that a particular relatedness proportion was not used in the study. SOA = stimulus onset asynchrony; RP = relatedness proportion; LDT = lexical decision task; Exp. = experiment.
[a] Strong associates only. [b] Clear targets only. [c] High dominance exemplars only. [d] Results collapsed over three nonword ratio conditions. [e] Results collapsed over presence or absence of nonwords in stimulus list. [f] Degraded targets only.

RPs. Thus, RP effects in the LDT can be due either to conscious expectancy or to semantic matching.

Neely (1977, 1991) argued that semantic matching occurs only at long SOAs, because at short SOAs prime processing is not complete. Indeed, he showed evidence that a marker of semantic matching, called the *nonword facilitation effect* (in which people respond to a nonword faster following an unrelated prime than following a neutral prime), emerged only at relatively long SOAs (400 ms or more). Neely et al. (1989) provided evidence that semantic matching was a strategic effect separate from expectancy by showing that priming in the LDT, from category primes to low-dominance exemplars (which should not be generated in an expectancy set), was influenced selectively by fluctuations in the nonword ratio but not by variations in RP. However, priming for high-dominance exemplars was influenced by both RP and nonword ratio variation. This finding is congruent with both a prelexical expectancy strategy, in which high-dominance exemplars are generated from the category prime, and a postlexical semantic-matching strategy, in which presence or absence of a relation between targets and primes is used to bias a word-or-nonword response.

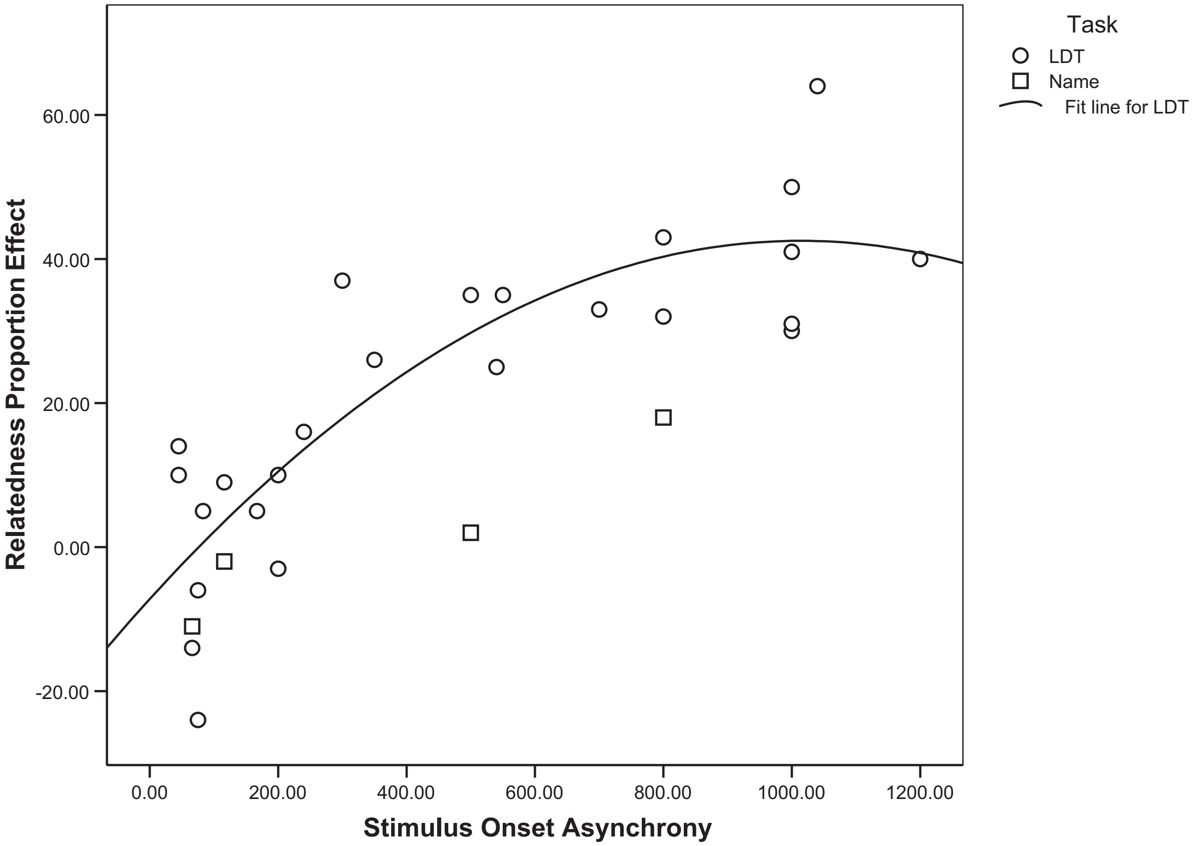

Figure 1. Results of previous manipulations of relatedness proportion in semantic priming experiments as a function of stimulus onset asynchrony and task. LDT = lexical decision task.

Keefe and Neely (1990) used the regression equations derived from Neely et al.'s (1989) LDT experiment to predict priming in pronunciation. Priming effects for high- and low-dominance exemplars were within 1 ms of the values predicted on the basis of Neely et al.'s equations, which involved RP (but not nonword ratio) as a predictor. Moreover, neither nonword facilitation nor an RP effect for low-dominance exemplars (effects attributed to a semantic-matching process) was produced in pronunciation. These findings suggest that the same expectancy-generation process occurs in both pronunciation tasks and LDT tasks, with LDT experiments producing an additional semantic-matching strategy.

In contrast to Neely and colleagues, de Groot (1984) proposed that this semantic-matching process was not a conscious strategy but a function of ordinary language comprehension. This proposal was based on the fact that she found a significant RP effect at 240 ms when using the LDT. According to both models, this semantic-matching process facilitates responding in LDT only, because in a naming task knowing that the prime and target are related per se does not aid in producing the target's pronunciation. Thus, more RP studies with pronunciation are needed to show whether RP effects at SOAs of between 200 and 300 ms are due to semantic matching or to expectancy generation.

Bodner and Masson (2003)

As can be seen at the top of Table 1, the significant RP effects obtained by Bodner and Masson (2003) with a 45-ms SOA stand in stark contrast to the numerically negative RP effects obtained from other LDT studies with a short SOA. This difference is likely due to Bodner and Masson's combination of using very-brief-duration primes (45 ms) and flanking each target word with *&&&* symbols. Although they presumably flanked the targets to minimize the perceptibility of the preceding primes, this flanking likely also lowered the perceptibility of the targets. The use of degraded targets has previously been argued to boost masked priming (Balota & Yap, 2006; Bodner & Masson, 1997) as well as to encourage people to rely more on using primes to identify targets (Bodner & Masson, 2003; Stolz & Neely, 1995; Whittlesea & Jacoby, 1990). It is likely that such a prime-recruitment process is both automatic and unconscious, as Bodner and Masson's results were primarily due to participants who were not consciously aware that primes had been flashed. Bodner and Masson argued that this prime-recruitment process depends on prime validity (the overall percentage of trials in a block that are related to their targets), such that the higher the RP, the more participants make use of primes to aid in identifying targets (see Stolz, Besner, & Carr, 2005, for a similar argument). Finally, this RP-sensitive prime recruitment is argued to occur for both clear and degraded targets, although target degradation may exaggerate this process (Bodner & Masson, 2003; Stolz et al., 2005).

Because RP has always been measured between blocks (and usually between subjects as well), the probability that an upcoming trial will be related has been perfectly confounded with the overall prime validity. As a result, the existence of an automatic prime-recruitment process at the high RP could give the *illusion* that participants consciously take note of the increase in RP and, as a result, engage in an effortful expectancy-generation strategy. This possibility prevents researchers from using RP effects at any SOA as a signature of conscious strategy usage when RP is manipulated across different participants or across different blocks (as has always been the case).

Current Study

The researcher's main goal in the current study was to design and test a semantic-priming paradigm in which differences in priming across RPs should be produced exclusively by conscious expectancy, rather than by automatic prime retrieval or by strategic semantic-matching processes. This was accomplished in two ways. First, this study used a pronunciation task, rather than an LDT, to prevent the participant's use of an alternative semantic-matching strategy that is usually effective on binary decision tasks. Second, RP was manipulated within a block of trials in which the overall prime validity was maintained at 50%. This was done by presenting prime words in different colors, such that each color was associated with a different RP. This color-cuing procedure improves upon previous RP manipulations in unconfounding the probability that an upcoming trial will be related with the overall prime validity. As a result, an automatic prime-recruitment process (which is based on overall prime validity; Bodner & Masson 2003) should occur equally under high- and low-RP conditions. Any observable RP effects should therefore reflect the participant's ability to engage in the effortful expectancy-generation process, with the prime color cuing the participant as to the likely effectiveness of such a strategy.

Attentional Control and the Prefrontal Cortex

The current color-cued RP task was included within a battery of tasks designed to measure attentional control. The attentional-control measure was included to validate the assumption that RP effects measured in this paradigm reflect an effortful expectancy-generation process rather than an automatic process, such as episodic prime recruitment. There is strong neurological evidence that the effortful process of generating and maintaining semantic information (the presumed process underlying expectancy) draws heavily on the prefrontal cortex (PFC; Henry & Crawford, 2004; Martin, 2005; Mummery, Patterson, Hodges, & Price, 1998; Rossell, Price, & Noble, 2003; Wagner, Bunge, & Badre, 2004), a brain area known to reflect attentional control (see Kane & Engle, 2002, for a review). For example, PFC is active when people are asked to generate synonyms (Klein et al., 1997), members of a category (Henry & Crawford, 2004), or a use for common objects (Peterson, Fox, Posner, Mintun, & Raichle, 1988). A study by Shivde and Thompson-Schill (2004) suggested that PFC is also critical for maintaining semantic information over a delay in working memory. In a delayed-judgment task, participants were asked to maintain either the sound or the meaning of a word across a 10-s interval. They then judged whether a target was related by sound or by meaning to the maintained item. Using an event-related functional magnetic resonance imaging design, Shivde and Thompson-Schill found bilateral activation in inferior PFC during the maintenance period only when participants maintained the meaning of the word (rather than the sound).

Because individuals differ greatly in their PFC functioning (Braver & Cohen, 2000; Gazzaniga, Ivry, & Mangun, 1998; Kane & Engle, 2002; Norman & Shallice, 1986) and because this difference underlies individual differences in attentional control (Kane & Engle, 2002), it is predicted that they should differ in their ability to engage in the effortful process of generating and maintaining semantic targets in the current paradigm. According to Kane and Engle (2002), the role of PFC (especially dorsolateral PFC) is to maintain information in a highly accessible state despite environmental or habitual distractions. Moreover, they view this ability as the core, domain-independent, attentional-control component of working memory capacity, a modern fluid intelligence measure that taps both short-term storage and executive (attentional) control. For instance, in the operation-span task of working memory capacity (Turner & Engle, 1989), participants must maintain a series of unrelated words in memory while simultaneously solving arithmetic problems.

Previous research by Engle and colleagues has shown that individuals low in working memory capacity are impaired on tasks, such as verbal fluency (Rosen & Engle, 1997), the Stroop task (Kane & Engle, 2003), and the antisaccade task (Kane, Bleckley, Conway, & Engle, 2001), that require participants to maintain information in working memory while performing an ongoing task. The verbal-fluency task requires participants to generate as many members of a specific category as possible within a specified time frame and requires their maintenance of previously generated items in order to avoid repetitions. The Stroop task (Stroop, 1935) requires participants to name the color in which a word is printed while they avoid the habitual response of naming the identity of the word. The antisaccade task requires participants to generate an eye movement (saccade) to the direction opposite to a peripheral abrupt-onset cue while they avoid the habitual response of looking toward the cue. If a participant is distracted during either the Stroop or the antisaccade task, the goal is often lost from working memory, and the participant slips into performing the automatic response.

In their review of studies examining PFC activity across individuals and across tasks, Kane and Engle (2002) concluded that individuals with low working memory capacity show patterns of cognitive performance similar to those of patients with lesions to their PFC. Such patients have been shown to perform poorly on verbal-fluency tasks (Pendleton, Heaton, Lehman, & Hulihan, 1982) and to have exaggerated error rates in both the Stroop (Vendrell et al., 1995) and the antisaccade tasks (Fukushima, Fukushima, Miyasaka, & Yamashita, 1994). Moreover, brain imaging studies on healthy adults have revealed PFC involvement in all three tasks (Henry & Crawford, 2004; MacDonald, Cohen, Stenger, & Carter, 2000; Sweeney et al., 1996). Thus, there is convincing evidence that (a) PFC is activated during the attentionally demanding process of maintaining information in working memory and (b) individuals differ in their ability to engage in such effortful processing.

Prefrontal Cortex and Semantic Priming

Given the above-mentioned implication that attentional control is required for an expectancy mechanism, one should hope to find PFC involvement in semantic-priming tasks that encourage such a strategy. Indeed, neuroimaging studies on semantic priming have revealed that the left PFC, along with the anterior cingulate cortex, is active during semantic-priming tasks when they are performed under strategic conditions (i.e., long SOA and high RP; Mummery, Shallice, & Price, 1999; Rossell, Bullmore, Williams, & David, 2001; Rossell, Price, & Noble, 2003). Rossell et al. (2003) argued that PFC (in particular, Brodman's area 45/47) performs an executive role in the selection or retrieval of semantic information.

Although neuroimaging work suggests that PFC is occasionally involved in semantic-priming performance under strategic conditions, it does not provide direct evidence that RP effects are determined by the differential engagement of a strategic expectancy-generation strategy. The current study is designed to provide such direct evidence by examining how individual differences in attentional control relate to individual differences in the magnitude of priming under high- versus low-RP conditions. In the current study, the researcher used performance on the attentional control battery (described below) to examine the extent to which increases in RP effects would correspond to increases in AC.

In addition to the color-cued RP manipulation, blocks of priming trials were presented with either a 267-ms SOA or a 1,240-ms SOA. As discussed previously, PFC is involved when people are asked to generate related items. It is therefore likely that individuals differ in the speed at which such generation is possible. The 267-ms SOA was chosen because it is at the lowest boundary at which significant RP effects begin to emerge. As can be seen from Table 1, RP effects increase from a nonsignificant 10-ms effect at 200 ms to significant effects of 16 and 37 ms at SOAs of 240 and 300 ms, respectively. It is likely that RP effects at these short SOAs are driven primarily by those individuals who can quickly make use of primes to generate related associates. As the SOA increases further, a greater proportion of individuals can likely begin the generation process before the onset of the target. However, at longer delays, individuals must not only generate associates but also maintain them in working memory while awaiting the target. Indeed, as discussed previously (and as shown in Figure 1), RP effects do not increase significantly between durations of 400 and 1,200 ms. For instance, Hutchison et al. (2001) found a nonsignificant 5-ms RP effect with an SOA of 167 ms but found significant (and statistically equal) RP effects of 37 and 40 ms across their SOAs of 300 and 1,200 ms. This pattern would be predicted if AC differences influenced RP effects more strongly at the SOA extremes. For this reason, the 1,240-ms SOA was also chosen, presumably to tap individual differences in the ability to generate semantic associates and to maintain them in working memory across a delay.

Overall, it was predicted that participants should show an RP effect, with more priming from high-RP colored primes than from low-RP colored primes. Also, because RP effects were predicted to reflect conscious expectancy generation, it was predicted that individual differences in AC should determine the size of RP effects. Those high in AC should show greater RP effects at both SOAs, with individual differences at the 267- and 1,240-ms SOAs reflecting the ability to quickly generate versus maintain semantic associates in working memory.

Experiment 1

Method

Participants

A sample of 224 male and female Montana State University undergraduates participated for partial completion of a research requirement for an introductory psychology class. All were native English speakers with normal or corrected-to-normal vision. The data from 12 participants were not analyzed because of their failure to complete all four of the required tasks.

Cued-RP Priming Task

Design. The color of each prime word indicated whether it would likely be followed by a related (high-RP) or an unrelated (low-RP) target. The SOA between the prime and the target was either 267 or 1,240 ms, and targets were either related or unrelated to their primes. RP and relatedness were manipulated within subjects and within blocks. SOA was also manipulated within subjects but across blocks.

Stimuli. The researcher selected 180 strongly associated prime–target pairs from those used by Hutchison, Balota, Cortese, and Watson (in press) for use in this study. Of these pairs, 80 were selected as critical items, and 100 were selected as filler items. For the critical trials, half of the prime words were presented in green, and half were presented in red. In addition, half were related to their targets, and half were unrelated. Unrelated trials were created by re-pairing the related targets with different primes. In each color, 50 filler pairs were included to increase or decrease the RP for that color. For example, if a participant was told that green primes were highly likely to be followed by related targets, the primes for the 50 related filler trials would all be presented in green, whereas the primes for the 50 unrelated trials would all be presented in red. The resulting RPs were either .78 or .22.

Eight lists were created to counterbalance the critical-word pairs across the eight experimental conditions created by the RP, SOA, and relatedness conditions. Each participant saw each prime and target word only once during the experiment. Prior to receiving each 90-trial experimental block, participants received a block of 8 practice trials for each SOA, which had nearly the same conditional RPs as the experimental trials.

Procedure. Each individually tested participant was seated approximately 60 cm away from a video graphics array monitor; instructions were displayed on the monitor and were also paraphrased by the experimenter. Participants were informed that they would see an uppercase word in either green or red ink followed by a lowercase word in white ink. They were instructed to read the colored uppercase word silently to themselves and to name the lowercase word as quickly and as accurately as possible. They were further told that the color of the uppercase word would cue the probability that the lowercase target would be related. Half of the participants were told, "If the uppercase word is green, then 80% of the lowercase targets will be related, and if the uppercase word is red, then 80% of the lowercase targets will be unrelated." The other half received the opposite instructions. These 80% estimates were close to the actual 78% color-cued RPs used in the experiment. Thus, experience in the practice and experimental trials should have reinforced these instructions.

All stimuli were presented using E-Prime software (Schneider, Eschman, & Zuccolotto, 2002), and responses were coded by a Model 300 Psychology Software Tools serial-response box. Each trial contained the following events: a 600-ms fixation point (*); a red or green prime presented for 160 ms; an interstimulus interval of 107 or 1,087 ms; and the target word presented for 2,500 ms, or until a response was given. All stimuli were presented centered on the display monitor. Participants were instructed to pronounce the target word as quickly and accurately as possible. After an additional 300-ms blank screen, the participants were asked to code the response, via a keypress, as (a) correct pronunciation, (b) unsure of pronunciation, (c) mispronunciation, or (d) extraneous voice-key triggering (i.e., if the microphone failed to detect the voice or if it detected some extraneous sound). Participants received training during practice trials to ensure that they understood the importance and use of the coding scheme. This coding procedure has already been demonstrated to be successful in large-scale naming studies by Spieler and Balota (1997) and Balota, Cortese, Sergent-Marshall, Spieler, and Yap (2004). The coding of the response triggered a 2,000-ms intertrial interval. Self-paced rest breaks were given every 40 trials.

Attentional Control Battery

OSPAN task. The OSPAN task was based on the version used by Engle and colleagues (Kane & Engle, 2003; Turner & Engle, 1989). In this task, participants see one operation string at a time (e.g., "is (8/2) + 3 = 7? fence") and must read the equation aloud, answer the equation aloud, and then read the word aloud. After a participant responds to a series of such strings (from two to six, with each set size presented three times during the task), he or she is presented with a row of question marks that cue the participant to recall the words in the order in which they were presented. Both the arithmetic problems and the words were generated by the experimenter but were similar in difficulty to those used by Engle and colleagues. Participants were encouraged to put equal emphasis on math performance and on word recall. An individual's OSPAN score was the sum of all recalled words from sets in which all words were recalled in the correct order.

To reduce the duration of the task, the researcher reduced the total number of sets from 15 to 12 by removing one of the two-item sets, one of the three-item sets, and one of the five-item sets. The total possible score thus ranged from 0 to 50 (relative to the 0–60 range when all sets are presented three times each).

Antisaccade task. The antisaccade task was based on versions employed by Kane et al. (2001) and Payne (2005). Participants were told that a large star would appear to the left or right of fixation and that this star would be immediately followed by a target stimulus (*O* or *Q*) on the opposite side of the screen. Participants were informed that their task was to look away from the flashed star in order to identify the target before it disappeared. Trials began with a white fixation (+) presented on a gray background for either 1,000 or 2,000 ms. Following the fixation, a white star (*), in 30-point Courier New font, appeared 3° to the left or right of fixation for 300 ms. Both star orientation (left or right) and star delay (1,000 or 2,000 ms) varied randomly on a trial-by-trial basis to prevent participants from anticipating when or where the star would appear. Following the star, the target appeared 3° to the opposite side of fixation for 100 ms and was immediately replaced by a backward pattern mask (##). The pattern mask was displayed for 5,000 ms, during which time the participants were to press either the *Q* or the *O* key to indicate the identity of the target. The timing of the trials was designed such that if participants accidentally made a saccade toward (as opposed to away from) the star, they would not have time to plan and execute another saccade to the opposite side of the screen and reach the target. Participants completed a total of 56 trials: 48 experimental trials and 8 practice trials.

Stroop task. The Stroop stimuli were taken from Spieler, Balota, and Faust (1996) and consisted of either color words (*red, green, blue,* and *yellow*) or neutral words (*bad, deep, poor,* and *legal*) matched to the color words in onset-phoneme characteristics and printed-word frequency (Kucera & Francis, 1967). Participants received 152 experimental trials consisting of 32 neutral trials and 120 incongruent trials. The neutral trials contained the four neutral words presented twice in each color. The incongruent trials contained the four color words presented 10 times in each of the three incongruent colors (e.g., the word *red* presented in green, blue, or yellow). Experimental trials were presented in a fixed-random order with self-paced rest breaks every 32 trials. Participants were instructed to name the ink color, but not the word itself, and to respond as quickly and accurately as possible. Participants' RTs were recorded via a Psychological Software Tools serial-response box, and an experimenter coded each response as (a) correct response, (b) response error, or (c) microphone error. Response errors consisted of either responding with the wrong word (e.g., responding "green" to the word *green* written in blue) or responding with a blended word (e.g., "gre–blue"). The experimental trials were preceded by 16 practice trials (4 neutral and 12 incongruent) presented in a fixed-random order.

General Procedure

The three AC tasks were given prior to the cued-RP priming task for half of the participants and after the priming task for the other half of the participants. However, because presentation order did not interact with any other variables in the analysis, the data are collapsed across order of presentation in the *Results and Discussion* section. The entire session lasted approximately 1 hr.

Preliminary Data Analysis

Data scoring. For the cued-RP priming task and the Stroop task, the dependent measures were RT and percent errors in each condition. However, because error rates in the priming task were less than 1%, only the RT data are reported. For both tasks, only correct responses were considered for the RT analysis. A separate mean and standard deviation were computed for neutral and incongruent conditions in the Stroop task and for each SOA in the cued-RP priming task. Outliers in both tasks were removed with the modified nonrecursive procedure suggested by Van Selst and Jolicoeur (1994). This procedure removed 2.6% of the correct RTs in the cued-RP priming task and 2.7% of the correct RTs in the Stroop task. For the cued-RP priming task, priming effects were computed by subtracting the mean RT to target words in the related condition from target words in the unrelated condition. The RP effect was computed by subtracting the priming effect in the low-RP condition (RP = .22) from the priming effect in the high-RP condition (RP = .78). For the Stroop task, Stroop interference effects were computed by subtracting the mean RT (or percent errors) for neutral words from the mean RT (or percent errors) for incongruent color words.

The dependent variable for the OSPAN and antisaccade tasks was accuracy. The OSPAN score reflected the sum of all words recalled from sets in which all the words were recalled in the correct order. Because there were 12 total sets, with a mean of 4.17 trials per set, possible scores ranged from 0 to 50. The data from 1 participant were eliminated because of less than 85% accuracy on the math problems. An individual's antisaccade score reflected the percentage of targets (*O* vs. *Q*) correctly identified. Scores ranged from .40 to 1.0, with a score of .50 reflecting chance performance.

Principal components analysis. Intercorrelations across all dependent variables in the AC battery were examined. As each task should contain variability because of task-specific abilities (e.g., arithmetic ability in the OSPAN task, color vision in the Stroop task, visual acuity in the antisaccade task), it was important to perform a principal components analysis to extract out common variance between the tasks. This common variance more accurately reflects one's degree of AC than does one's performance in any one task alone (see Conway, Kane, & Engle, 2003, for a discussion). Although one is never certain what a "component" represents in such an analysis, a distinct pattern is predicted. In particular, higher values for the Stroop interference measures indicate worse AC (i.e., more interference from the incongruent word), whereas higher values in the antisaccade and OSPAN tasks indicate better AC. Thus, a component hypothesized to reflect AC should receive positive loadings for the antisaccade and OSPAN measures and negative loadings for the Stroop measures.

Results and Discussion

Attentional Control Battery

Descriptive statistics. Descriptive statistics for each of the AC tasks are presented in Table 2. In addition to the means, standard deviations, and ranges for each task, a measure of internal consistency is reported describing the results of odd–even split-half reliabilities. As expected, overall performance in the OSPAN task was slightly lower than that observed in other studies with lower- and upper-quartile cutoffs of 6 and 14, rather than the more typical cutoffs of around 9 and 18 (Kane & Engle, 2003; Kane et al., 2001). This lower performance was predicted, given that the current version included fewer sets of trials, resulting in a maximum score of 50 rather than 60. In addition, the removal of a 2-item set and a 3-item set made this version more difficult on average (4.17 items per trial) than the traditional version (4.0 items per trial). The Stroop interference effect was significant both by RTs and errors (both $ps < .001$). As can be seen in Table 2, the split-half reliabilities were good for the OSPAN and antisaccade tasks but were lower for the Stroop measures.

Correlations. The correlations among AC measures are presented in Table 3. As can be seen, some of the measures were correlated with one another. In particular, there were significant correlations between OSPAN and antisaccade and between antisaccade and Stroop interference measured in RTs. It is interesting that OSPAN did not correlate with Stroop interference, even though both presumably require AC. A likely explanation for this null correlation is that the current experiment included a high proportion of incongruent trials. As argued by Kane and Engle (2003), a high proportion of incongruent trials reinforce the task goal of naming the color, rather than the word, on every trial, because participants constantly deal with conflicting responses (the automatic "word" response versus the required "color" response). When the proportion of incongruent-to-congruent trials is reduced, greater demand is placed on the participant's working memory to actively maintain the task goal across congruent (i.e., nonconflicting) trials. In support of this claim, Kane and Engle (2003, Experiments 1 and 2) found no differences in Stroop interference in individuals with high or with low working memory capacity when (a) none of the word stimuli matched the color (0% congruent condition) and (b) participants received a large number of trials with incongruent stimuli. Differences between span groups emerged only when congruent items were included in the stimulus list. (It should be noted that the current experiment was run prior to publication of Kane & Engle, 2003.) Finally, Stroop interference measured in error rates did not correlate with any of the other AC measures. This result may also be due to the lack of congruent items or instead solely to the low reliability of this measure.

Principal components analysis. The relationship between AC measures was investigated using principal components analysis, the results of which are presented in Table 4. Several criteria revealed that there was only one significant component, which

Table 2
Descriptive Statistics for the Attentional Control Battery in Experiments 1 and 2

Task	*M*	*SD*	Range	Internal consistency
		Experiment 1		
OSPAN	11.43	7.56	0, 38	.701[a]
Antisaccade	70.45	13.72	.40, 1.00	.754[b]
Stroop RT	33.92	41.00	−147, 195	.554[b]
Stroop error	1.58	2.52	−8.59, 12.54	.483[b]
		Experiment 2		
OSPAN	10.31	7.40	0, 39	.701[a]
Antisaccade	73.76	12.94	.38, 1.00	.691[b]
Stroop RT	140.19	61.80	2, 350	.677[b]
Stroop error	5.72	4.94	0.00, 36.11	.676[b]

Note. RT = reaction time.
[a] Reported by Conway et al. (2005). [b] Based on odd–even split-half correlation with Spearman–Brown correction.

accounted for 32% of the variance in performance across tasks.[2] The pattern of task loadings suggests that this component indeed reflects AC, with OSPAN and antisaccade loading positively and Stroop interference (in RTs) loading negatively. The failure of the Stroop error measure to load on the AC component is not surprising, given the lack of any correlation between this measure and the other AC measures (see Table 3). Individual scores on this AC component ranged from -2.75 to 4.08.

Cued-RP Priming Task

Group means calculated on the basis of individual participants' trimmed-mean RTs are presented in Table 5. Unless otherwise noted, each effect called statistically significant is associated with a two-tailed $p < .05$. RTs were analyzed with the general linear model, with SOA, RP, and relatedness treated as categorical within-subjects factors and AC treated as a continuous between-subjects factor. Allowing AC to remain a continuous variable is advantageous over grouping the data into extreme groups (quartile, tertile, or median splits), because such categorical grouping (a) reduces the power to detect true relationships between variables and (b) can produce effects that do not truly exist when the entire sample is considered (Cohen, Cohen, West, & Aiken, 2003). Therefore, all statistical interactions were tested using the entire range of participants' AC scores. However, for simplicity of presentation, the data are also reported in Table 5, with AC broken down by high, moderate, and low groups.[3]

Overall, there was a main effect of AC, $F(1, 210) = 5.28$, $MSE = 67{,}994$, such that lower AC individuals tended to respond more slowly than did higher AC individuals. Main effects of SOA and relatedness were also observed, with participants responding more quickly to related targets than to unrelated targets, $F(1, 210) = 214.81$, $MSE = 979$, and more quickly at the short SOA than at the long SOA, $F(1, 210) = 4.10$, $MSE = 7{,}561$. In addition, there was a significant SOA × Relatedness interaction, $F(1, 210) = 4.68$, $MSE = 1{,}049$, with individuals showing more priming at the longer SOA. Moreover, there was a marginally significant RP effect—i.e., RP × Relatedness interaction, $F(1, 210) = 3.03$, $MSE = 940$, $p < .09$—indicating more priming under high-RP conditions. A significant 121 out of the 212 total participants (57%) showed more priming when the RP was high than when it was low ($z = 2.06$, $p < .04$). This RP effect was significant at the long SOA (9 ± 8 ms) but not at the short SOA (1 ± 9 ms). (Hereafter, when the current study reports an $X \pm Y$-ms effect, Y refers to the 95% confidence interval.) However, the three-way interaction between RP, relatedness, and SOA failed to reach significance ($p > .20$).

Table 3
Intercorrelations Among Attentional Control Battery Tasks in Experiments 1 and 2

Task	1	2	3	4
		Experiment 1		
1. OSPAN	—	$.19^{**}$	.00	.01
2. Antisaccade		—	$-.19^{**}$	.05
3. Stroop RT			—	.07
4. Stroop error				—
		Experiment 2		
1. OSPAN	—	$.31^{**}$	$-.25^{**}$	.02
2. Antisaccade		—	$-.22^{**}$	$-.13$
3. Stroop RT			—	$.16^{*}$
4. Stroop error				—

Note. RT = reaction time.
$^{*} p < .05$. $^{**} p < .01$.

Table 4
Unrotated Component Matrices for Experiments 1 and 2

Task	Experiment 1	Experiment 2
OSPAN	.57	.69
Antisaccade	.80	.71
Stroop RT	$-.56$	$-.68$
Stroop error	.03	$-.38$

Note. The extraction method was principal component analysis. RT = reaction time.

Of most importance, the RP effect significantly interacted with AC, $F(1, 210) = 7.52$, $MSE = 941$, with RP effects increasing linearly with increases in AC ($r = .186$, $p < .01$). This significant interaction is shown in Figure 2. When separated by SOA, the correlation between RP effects and AC was significant at the 1,240-ms SOA ($r = .147$, $p < .04$) and was marginally significant at the short SOA ($r = .114$, $p < .10$). Although a correlation of .186 between AC and RP effects may not seem impressive, it should be noted that reliability of priming effects is typically weak (Hutchison et al., in press; Stolz et al., 2005).[4] When testing young adults in the LDT, Stolz et al. (2005) demonstrated that when 50% of the word trials were related (the same overall RP used in the present study), test–retest reliability effects were .30 and .27 for their 200- and 800-ms SOAs, respectively. Similarly, using a naming study and many of the same items used in the current study, Hutchison et al. (in press) showed split-half reliabilities of .35 and .73 for their young adults in the 250- and 1,250-ms SOAs, respectively. Given that priming effects themselves tend to show reliabilities not much greater than .30 and that RP effects reflect a further difference score above and beyond simple priming effects, the .186 correlation of RP effects with AC reveals that indeed AC was likely capturing much of the explainable (i.e., predictable) variability in priming across participants.

As can be seen in Table 5, the pattern of RP effects is quite different for the three AC groups. The high-AC group showed significant RP effects at both the short SOA and the long SOA, the

---

[2] The reasons not to include a second component in the solution are as follows. The second highest component (a) had an eigenvalue barely above 1 (i.e., 1.062); (b) was not easily interpretable; (c) was correlated with Component 1 ($r = -.25$), according to direct oblimin rotation; (d) was loaded upon by fewer than three of the four variables; (e) contained no factor loadings higher than .30, according to principal-axis factoring (usually considered the cutoff point for an important loading); and, most important, (f) did not replicate in Experiment 2.

[3] It should be noted that the RP Effect × AC interaction was significant regardless of whether AC was treated as a continuous variable or was instead grouped into a tertile split (as shown in Table 5).

[4] Because the current study included only 10 items per condition, it was not deemed appropriate to conduct a split-half reliability estimate. Splitting each condition into two sets of 5 items would greatly underestimate the true consistency of the measure.

Table 5

Mean Reaction Times (ms), Percent Errors, and Priming Effects in the 267-ms SOA and 1,240-ms SOA Conditions in Experiment 1 as a Function of Attentional Control Group

SOA	Condition	RP = 22.2	RP = 77.8	RP effect
		High AC		
267 ms				
	Unrelated	529	539	
	Related	519	516	
	Priming	+10†	+23*	+13*
1,240 ms				
	Unrelated	536	543	
	Related	518	507	
	Priming	+17*	+36*	+19*
		Moderate AC		
267 ms				
	Unrelated	527	525	
	Related	510	505	
	Priming	+17*	+20*	+3
1,240 ms				
	Unrelated	543	544	
	Related	524	517	
	Priming	+19*	+27*	+8
		Low AC		
267 ms				
	Unrelated	579	574	
	Related	551	558	
	Priming	+28*	+16*	−12
1,240 ms				
	Unrelated	590	589	
	Related	563	561	
	Priming	+27*	+28*	+1

Note. SOA = stimulus onset asynchrony; RP = relatedness proportion; AC = attentional control.
* $p < .05$. † $p < .10$.

moderate-AC group showed numerically positive but nonsignificant RP effects at both SOAs, and the low-AC group showed a nonsignificant negative effect at the short SOA and little-to-no effect at the long SOA.

The opposite patterns for high- and low-AC individuals at the short SOA suggest that the null overall RP effect at the short SOA was due to positive effects for high-AC individuals being canceled by negative effects for low-AC individuals. This finding is of particular interest, given the earlier hypothesis that individuals likely differ in the speed at which they can strategically generate semantic associates. In fact, the steady increase in RP effects with SOA seen in Table 1 at SOAs under 400 ms may reflect steady increases in the percentage of participants capable of generating semantic associates; within each subject, it may reflect an increase in the number of primes for which the participant can successfully generate related targets.

At the long SOA, both high- and moderate-AC individuals appear capable of generating and maintaining expected targets (though the 8 ± 11-ms RP effect for moderate-AC individuals failed to reach significance), which produced an overall significant RP effect despite the null effect for low-AC individuals. The null 1 ± 15-ms RP effect for low-AC individuals suggests a problem in either generating or maintaining semantic associates in working memory. Given the numerically negative effect at the short SOA, it is likely that the problem for low-AC individuals was in the initial generation of associates, rather than in maintenance.

Three aspects of Experiment 1 make a strong case for conscious expectancy generation and maintenance as the likely mechanism underlying RP differences across colors. First, the significant overall RP effect at the long SOA occurred in a pronunciation task, which has been argued to be devoid of any strategic semantic-matching process (see Neely, 1991, for a review). Second, this conditional RP effect (on the basis of prime color) was unconfounded by the overall RP for a block of trials, which has been argued to influence an automatic prime-retrieval process. Third, and most interesting, this RP effect was linearly related to AC. As AC increased, so too did the size of the RP effect. This third piece of evidence indicates that the process of expectancy generation and maintenance is sufficiently effortful that it taps individual differences in PFC functioning.

The different numerical patterns for AC individuals across SOA are intriguing. At the long SOA, the RP effect was due primarily to high- and moderate-AC individuals, suggesting that a majority of participants could generate and maintain semantic associates over the 1,240-ms SOA. Indeed, at the long SOA, a significant 124 of the 212 total participants (59%) showed more priming under high-RP conditions than under low-RP conditions ($z = 2.47$, $p < .02$). However, at the short SOA, only the high-AC individuals showed a positive RP effect (13 ± 11 ms), whereas the low-AC individuals actually showed a numerically negative RP effect (−12 ± 20 ms). The opposite pattern of RP effects suggests that individuals may indeed differ in how quickly they can generate semantic associates. Indeed, if AC partially captures individual differences in the speed of semantic generation, the short-SOA data fit well with past research, with high-AC individuals showing positive RP effects reflective of longer SOAs and low-AC individuals showing negative RP effects reflective of very brief SOAs.

One potential concern for Experiment 1 was the lack of a significant three-way interaction between SOA, RP, and relatedness. However, this should only be observed if the short SOA was sufficiently brief to preclude successful conscious-expectancy generation. As discussed above, this was not the case for all individuals. Instead, most high-AC individuals could indeed generate targets within 267 ms. The lack of a three-way interaction with SOA is actually congruent with past research by Hutchison et al. (2001) with similar SOAs. Hutchison et al. found such a three-way interaction only when comparing RP effects at their 167- and 1,200-ms SOAs. There was no difference in RP effects when they compared their 300-ms SOA with their 1,200-ms SOA.

Experiment 2

The significant RP effect at the 267-ms SOA for the high-AC participants suggests that some people may be able to generate semantic associates prior to the 300–400-ms cutoff typically proscribed in priming studies. This seems especially true, given that the cued-RP task in Experiment 1 involved additional processing, in which participants first had to identify the color of the prime and then had to retrieve the appropriate color–RP mapping from memory before they could discern whether to generate semantic associates. This processing may have increased the SOA necessary to

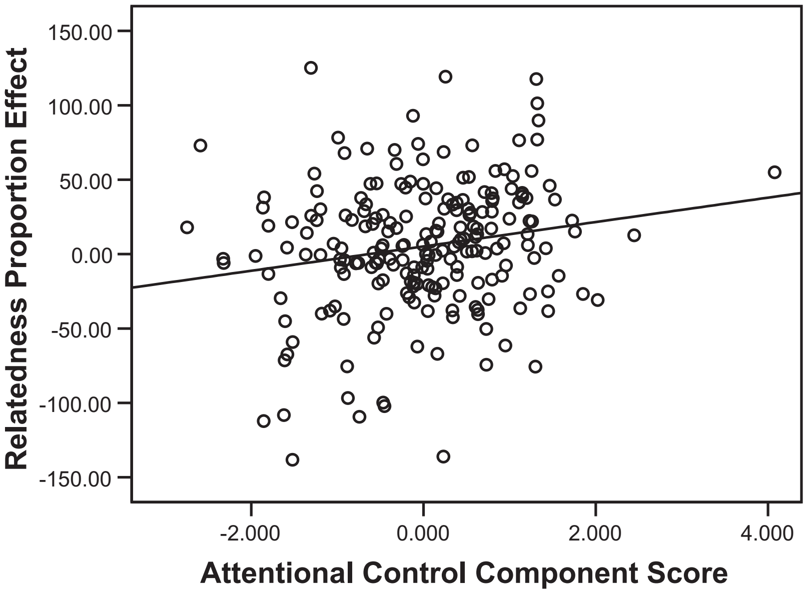

Figure 2. Relatedness proportion effects in Experiment 1 as a function of attentional control component scores.

find effects of expectancy. Moreover, the need to retrieve the color–RP mapping may have depended on AC, with only high-AC individuals maintaining the mapping in working memory across trials. This requirement could add to the differential RP effects across AC individuals. For low-AC individuals, the time spent retrieving the color–RP mapping could delay (or even prevent) the expectancy-generation process. Such concerns were addressed in Experiment 2 by providing individuals with an explicit cue prior to each trial, indicating both the color of the upcoming prime and the RP associated with that color. This change should allow individuals to decide ahead whether to engage in expectancy generation from the upcoming prime.

Method

Participants

A sample of 157 male and female Montana State University undergraduates participated for partial completion of a research requirement for an introductory psychology class. All were native English speakers with normal or corrected-to-normal vision. The data from 6 participants were not analyzed because of their failure to complete all of the required tasks.

Cued-RP Priming Task

The cued-RP priming task in Experiment 2 was the same as that in Experiment 1, with one exception: Participants were cued for 1,000 ms prior to each trial with either the phrase “80% Related” or the phrase “80% Unrelated.” This cue was presented in the same color as the uppercase prime and served to alert participants as to which type of trial was coming up and to remind them of the appropriate color–RP mapping.

Attentional Control Battery

The antisaccade and OSPAN tasks in Experiment 2 were the same as those in Experiment 1. However, the number of incongruent trials in the Stroop task was reduced from 128 to 36, and the number of neutral trials was increased from 32 to 45. Of most importance, 36 congruent trials (the word *red* written in red) were added. These changes should increase the demand to maintain the appropriate task goal in working memory, thus increasing the size of Stroop interference in low-AC participants (Kane & Engle, 2003).

General Procedure

As in Experiment 1, participants completed the three AC tasks either before or after the cued-RP priming task. Again, presentation order did not interact with any other variables in the analysis, so the data are collapsed across order for presentation in the *Results and Discussion* section. The entire session lasted approximately 1 hr.

Preliminary Data Analysis

The AC measures were analyzed in the same manner as in Experiment 1, with one exception: The addition of the congruent condition in the Stroop task allowed for the computation of not only interference effects (incongruent color words minus neutral words) but also facilitation effects (neutral words minus congruent color words) and Stroop effects (incongruent color words minus congruent color words).

Results and Discussion

Attentional Control Battery

Descriptive statistics. Descriptive statistics for each of the AC tasks are presented at the bottom of Table 2. The results of Experiment 2 closely agree with those of Experiment 1, with one exception: The Stroop effect, measured in both RTs and errors, was about four times larger in Experiment 2 than in Experiment 1. This increase was likely caused by two changes in procedure. First, the number of incongruent trials in Experiment 2 was reduced from 120 to 36, which gave participants less practice with incongruent items. Second, 36 congruent trials were included, which should have increased the need for participants to maintain the task goal of naming the color in working memory; their inclusion also allowed for the calculation of a more traditional Stroop effect, rather than interference alone. Therefore, the Stroop effect reflects not only interference from incongruent trials but facilitation from congruent trials (relative to neutral). As argued by MacLeod (1991) and Kane and Engle (2003), this facilitation for congruent trials may reflect fast (or clean) errors, in which participants actually respond with the name of the word itself, rather than with the color. Because there is no way to measure errors on congruent trials, this is manifested as an RT effect.

Examination of the data suggests that the increase in Stroop effect from Experiment 1 to Experiment 2 is not solely due to the baseline from which to calculate interference (neutral vs. congruent). Although the overall 140-ms Stroop effect includes both facilitation (41 ms) and interference (100 ms), the 100-ms interference effect is still three times larger than that obtained in Experiment 1, $t(363) = 12.7$, $p < .001$. Similarly, the 5.0% interference effect in errors from Experiment 2 is over three times greater than the 1.6% effect in Experiment 1, $t(363) = 8.8$, $p < .001$. This is likely because Experiment 2 increased the demand for goal maintenance by including congruent trials and by giving participants less practice on incongruent trials (see Kane & Engle, 2003, for a further discussion).

Correlations. The correlations among AC measures are presented in Table 3. In general, the pattern of correlations replicated that found in Experiment 1. In fact, the correlations found in Experiment 2 were slightly higher than those found in Experiment 1. For example, the correlation between OSPAN performance and antisaccade performance jumped from .19 in Experiment 1 to .31 in Experiment 2. The major difference between Experiments 1 and 2 is the pattern of correlations for the Stroop effect. Whereas Stroop interference did not correlate with OSPAN in Experiment 1, there was a significant negative correlation in Experiment 2, $r(152) = -.19$, $p < .03$. Although not significant, the correlation between OSPAN and facilitation was in the same direction, $r(152) = -.11$, $p > .16$. When interference and facilitation were combined into an overall Stroop effect, the correlation with OSPAN increased, $r(152) = -.25$, $p < .005$.

Principal components analysis. The relationship between the three AC measures was again investigated using principal components analysis, the results of which are presented in Table 4. Several criteria again revealed a single component, with OSPAN and antisaccade loading positively and Stroop RT loading negatively. In addition, Stroop errors loaded negatively in Experiment 2, consistent with the claim made above that the procedure in Experiment 2 increased the need for goal maintenance in this task. The higher loading of both Stroop measures may partly be due to increases in internal consistency for these measures, which likely resulted from the methodological changes mentioned above. Individual scores on this AC component ranged from −3.78 to 2.74, and individuals were classified as high, moderate, or low in AC on the basis of this score.

Table 6

Mean Reaction Times (ms), Percent Errors, and Priming Effects in the 267-ms SOA and 1,240-ms SOA Conditions in Experiment 2 as a Function of Attentional Control Group

SOA	Condition	RP = 22.2	RP = 77.8	RP effect
		High AC		
267 ms				
	Unrelated	500	506	
	Related	487	482	
	Priming	$+13^*$	$+24^*$	$+11^*$
1,240 ms				
	Unrelated	518	524	
	Related	497	488	
	Priming	$+21^*$	$+36^*$	$+15^*$
		Moderate AC		
267 ms				
	Unrelated	523	527	
	Related	510	507	
	Priming	$+13^*$	$+20^*$	+7
1,240 ms				
	Unrelated	526	529	
	Related	509	508	
	Priming	$+17^*$	$+21^*$	+4
		Low AC		
267 ms				
	Unrelated	537	525	
	Related	521	508	
	Priming	$+16^*$	$+17^*$	+1
1,240 ms				
	Unrelated	544	535	
	Related	517	518	
	Priming	$+27^*$	$+17^*$	−10

Note. SOA = stimulus onset asynchrony; RP = relatedness proportion; AC = attentional control.
$^* p < .05$.

Cued-RP Priming Task

Group means calculated on the basis of individual participants' trimmed-mean RTs are presented in Table 6. RTs were again analyzed with the general linear model, with SOA, RP, and relatedness treated as categorical within-subjects factors and AC treated as a continuous between-subjects factor. As with Experiment 1, overall RT decreased with increasing AC. In addition, participants responded more quickly to related targets than to unrelated targets and responded more quickly at the short SOA than at the long SOA. Moreover, as with Experiment 1, the effect of relatedness was greater at the long SOA than at the short SOA. These observations were supported by main effects of AC, $F(1, 149) = 6.48$, $MSE = 48{,}129$; SOA, $F(1, 149) = 3.37$, $MSE = 4{,}048$; and relatedness, $F(1, 149) = 124.32$, $MSE = 999$, and SOA × Relatedness interaction, $F(1, 149) = 4.26$, $MSE = 737$. The overall RP effect failed to reach significance, $F(1, 148) = 1.98$, $MSE = 744$, $p > .16$. However, there was again a significant RP × Relatedness × AC interaction, $F(1, 149) = 4.93$, $MSE = 744$. As shown in Figure 3, the RP effect again linearly increased across AC ($r = .177$, $p < .03$). When separated by SOA, it is apparent that this overall effect was primarily due to the correlation at the long SOA ($r = .185$, $p < .03$), as the short-SOA correlation was not significant ($r = .084$, $p > .30$). It is of interest that the correlation between AC and RP effects at the long SOA numerically increased from Experiment 1 to Experiment 2,

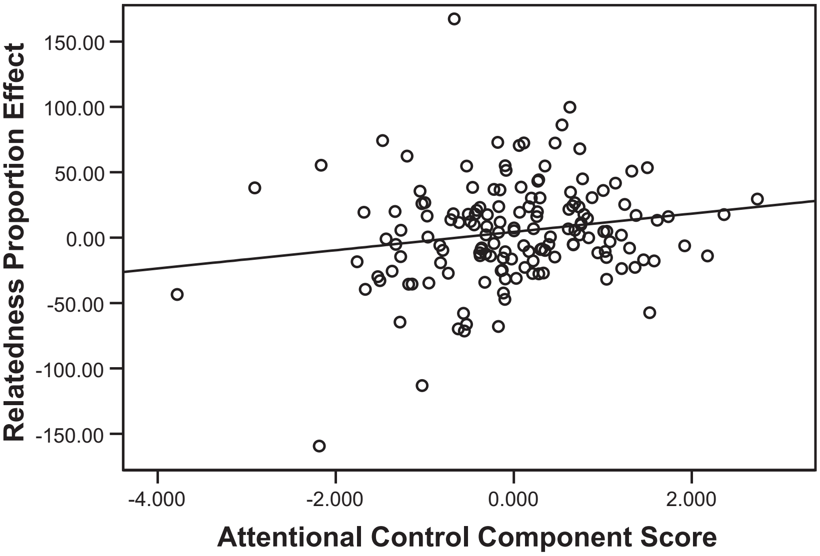

Figure 3. Relatedness proportion effects in Experiment 2 as a function of attentional control component scores.

whereas the correlation at the short SOA numerically decreased. There is likely a trade-off between generation and maintenance, in that the faster one can generate an associate, the longer that generated associate must be maintained in working memory before the target is shown. However, as noted previously, there is no evidence from either experiment that low-AC individuals generated semantic associates at any SOA.

Examination of Table 6 reveals once again that the pattern of RP effects is quite different for the three AC groups. The high-AC group again showed RP effects at both SOAs, and the moderate-AC group showed nonsignificant positive RP effects at both SOAs. The pattern for the low-AC group flipped from Experiment 1, with no effect at the short SOA and a numerical but nonsignificant negative RP effect at the long SOA. As with Experiment 1, it is clear that the RP effects were primarily produced by the high-AC individuals.

In contrast to Experiment 1, the opposite pattern of RP effects for high- and low-AC groups occurred at the long, rather than the short, SOA in Experiment 2. This finding suggests two important conclusions. First, the numerically negative RP effect for low-AC individuals in Experiment 1 was likely due either to the failure to maintain the appropriate color–RP mapping across trials or to the time required to prepare oneself to make use of an upcoming prime in generating semantic associates. The 1,000-ms precue likely reduced any interference experienced by moderate-to-low AC individuals, who needed to quickly decipher the prime's color and map it onto the appropriate RP contingency. However, it is important to note that the null RP effect for low-AC individuals at the short SOA suggests that they cannot generate semantic associates within 267 ms, even when precued with the appropriate color–RP mapping. Second, the significant difference in RP effects at the long SOA suggests that low-AC individuals indeed have trouble generating and maintaining semantic associates over time. In summary, the replication of Experiment 1 under precue conditions indicates that the linear relation between AC and RP effects is not simply due to low-AC individuals' failure to maintain the appropriate color–RP mappings across trials.

As was predicted in the introduction, it is indeed possible for high-AC participants to generate expected targets within 267 ms. Thus, one can conclude that the 300–400-ms cutoff for conscious strategy use is too liberal. Instead, as argued in the introduction, it is likely that no strict cutoff even exists. Conscious strategies, such as expectancy generation, likely vary across items, participants, and practice.

Baseline RT Concern

The finding that AC was negatively related to baseline RT in both experiments is a potential concern that may undermine the conclusion that RP effects require AC. This conclusion would be invalid if it were shown that faster RTs, in general, are associated with greater RP effects. However, such a finding is theoretically unlikely, as past researchers have demonstrated that priming effects tend to increase linearly with baseline RT (Faust, Balota, Spieler, & Ferraro, 1999; Hutchison et al., in press). To test whether the RP effect × AC interaction was merely a function of differences in baseline RT, this researcher conducted an analysis of variance, with baseline RT as a continuous between-subjects factors and SOA, RP, and relatedness as within-subjects factors. This analysis revealed that baseline RT did not influence the size of RP effects ($F < 1$). In addition, the significant overall correlation between AC scores and the size of the RP effect increased from $r = .183$ to $r = .190$ when variance that was due to overall RT was removed. Thus, the linear increase in RP effects with AC is not due to differences in overall RT across individuals.

General Discussion

As discussed by Bodner and Masson (2003) and Stolz et al. (2005), participants may unconsciously become sensitive to overall prime validity during a priming experiment. When the overall prime validity is high, an automatic prime-recruitment process may occur, in which participants retrieve the episodic memory of the primes in order to aid in identifying the target. The critical importance of such a process is that RP differences in priming likely reflect automatic as well as strategic processes when RP is manipulated between either subjects or blocks. Because of this, the ability to manipulate RP within subjects and within blocks in the current study is a substantial improvement over previous RP manipulations.

A similar difficulty in interpretation occurs when RP is manipulated within the LDT. As demonstrated by Neely et al. (1989), RP effects in the LDT are influenced not only by expectancy but by a semantic-matching process that occurs after target onset. This semantic-matching process is effective under high-RP conditions, because unrelated targets tend to be nonwords when an equal number of words and nonwords are used (as is typically the case). However, the strategy is less effective under low-RP conditions, because there is an approximately equal chance that an unrelated target is a word or a nonword. As a result, semantic matching adds to RP effects when an LDT is used.

As all previous RP experiments have used a between-blocks or a between-subjects design and over 90% of them have used a form of LDT, past RP effects reflect a combination of (a) automatic prime retrieval, (b) conscious expectancy generation, and (c) strategic semantic matching. By contrast, the current within-block RP-cuing procedure with a pronunciation task specifically isolates the conscious expectancy process. Because this RP effect is produced exclusively by an effortful expectancy-generation process, it is likely weaker in effect size than are RP effects from other procedures. On the other hand, because this paradigm investigates RP effects within subjects, researchers may be able to detect the effect with fewer total participants than are needed for an identical effect size manipulated between subjects (i.e., greater power). As a result, large sample sizes are probably necessary regardless of whether one manipulates RP with the traditional between-subjects paradigm or with the current RP-cuing paradigm. However, even though the cuing paradigm may not increase the power of RP effects overall, it is quite sensitive to differences in RP effects that result from individual differences in PFC functioning. Across both SOAs, in Experiments 1 and 2, RP effects were linearly related to individual differences in AC, such that moderate-AC individuals showed RP effects numerically higher than those shown by the low-AC group but lower than those shown by the high-AC group.

The current study also provides evidence against the existence of a fixed threshold, at which priming suddenly switches from automatic to strategic. Results from the current study demonstrate that expectancy generation is possible within 267 ms for high-AC individuals. RP effects at the 267-ms SOA were also marginally correlated with AC, adding credit to the claim that RP effects at this short SOA reflect individual differences in ability to quickly generate semantic associates. In addition to overall participant differences, expectancy generation has been demonstrated to depend on lexical and semantic characteristics of both primes and targets (see Hutchison et al., in press). Thus, the concept of an overall SOA threshold for expectancy generation is dangerously misleading. Instead, the ability to generate associates varies across individuals and items, with longer SOAs increasing the number of participants (and number of trials per participant) for which expectancy generation is possible. This argument against a threshold for enabling strategic-priming mechanisms is in accordance with arguments within the perception literature against a threshold at which stimulus identification switches from subliminal to conscious (see Bengson & Hutchison, in press, for more discussion of this issue).

Another potentially interesting finding from the current study was the numerically negative RP effects for low-AC individuals. This is a potentially important finding because (a) the studies summarized in Table 1 hint at negative RP effects from normal healthy adults at very brief SOAs and (b) Bushell (1996) previously observed a negative RP effect at a long SOA from patients with Broca's aphasia. That the performance of low-AC individuals would mirror that of patients with Broca's aphasia is intriguing and reinforces Kane and Engle's (2003) observation that individuals with low working memory often perform like patients with PFC damage. Furthermore, the fact that the negative RP effect in Experiment 2 occurred at the long, rather than the short, SOA raises the possibility that this is a deficit in maintenance rather than in generation. Because Bushell used only a long SOA, her results may have reflected such a maintenance problem. Future research is needed to explore both generation and maintenance in patients with Broca's aphasia, allowing us to see if such a deficit indeed exists. In addition, those conducting future studies with healthy young adults should include a moderate SOA (500–700 ms) to determine whether (a) low-AC individuals cannot generate any expectancies or (b) they can generate expectancies, but the expectancies from these individuals take longer and decay faster. The current design is unable to distinguish between these two possibilities.

It is interesting that only one previous study has examined individual differences in semantic priming as a function of working memory capacity. Kiefer, Ahlegian, and Spitzer (2005) gave participants both a forward and a backward digit-span task as well as a semantic-priming task. Using a .33 RP and an LDT, they found that high-AC individuals showed less priming than did low-AC individuals at a 700-ms SOA. Kiefer et al. argued that this was the result of a less focused semantic-prime retrieval for individuals with low working memory capacity. Results for the low RP trials in the current study replicate those of Kiefer et al., with greater priming for low AC (27 ± 8 ms) than for high AC (19 ± 6 ms) under low-RP conditions. However, this difference in priming is likely a simple function of differences in baseline RT (and variability) between the groups, rather than of differences in the focus of memory search. As mentioned previously, low-AC individuals in the current study were slower on average than were high-AC individuals. (Although Kiefer et al. reported only the priming effects in their priming task, rather than including raw RTs, it is likely that their participants with low working memory capacity were also slower in RT than were their participants with high working memory capacity, because the former participants were demonstrated to be slower on a Stoop task across all three congruency conditions: neutral, congruent, incongruent.) Faust et al. (1999) previously demonstrated a linear relation between a group's baseline RT and that group's numerical priming effect, when priming was measured as millisecond-difference scores between a related and an unrelated condition. Faust et al. argued that Group × Treatment interactions are not easily interpreted in the face of such differences in baseline RT; they recommend a *z*-score transformation of RTs in such cases, because it corrects for differences in processing speed across groups. The resulting priming score for each group (or individual) is expressed in standard deviation (SD) units. Using Monte Carlo simulations, Faust et al. demonstrated that this transformation effectively reduced Type I errors. When the Faust et al. *z*-score transformation is applied to the current data, priming effects under the low-RP conditions are identical for low-AC (.29 ± .08 SD units) individuals and high-AC (.29 ± .08 SD units) individuals. In contrast, group differences under high-RP conditions remain, with high-AC individuals demonstrating more priming (.46 ± .09 SD units) than do low-AC individuals (.28 ± .09 SD units). Thus, real differences between AC groups in semantic priming emerge only under high-RP conditions, which suggests that such differences are solely a function of effortful strategy use.

Future Directions

The ability to measure RP effects within subjects and within blocks opens up several avenues for future exploration. This procedure produces a purer measure of conscious expectancy than is seen in the standard between-blocks, between-subjects paradigm. Such a design lends itself quite readily to other general priming phenomena, as well as to studies examining aging or using brain imaging.

General Priming Phenomena

The current cued-RP paradigm is similar to Neely's (1977) classic opposition paradigm, in which he was able to dissociate effects that were due to expectancy from effects that were due to relatedness by using category primes (e.g., BODY) to cue participants to expect targets from a particular unrelated category (e.g., PART of a BUILDING). Neely (1977) provided evidence for a strategic expectancy component, finding facilitation only for expected targets (e.g., BODY– *window*) relative to a neutral baseline (e.g., XXXX– *window*) at relatively long SOAs (over 400 ms). Because there was no preexisting relation between primes and targets in this condition, priming must have been driven by conscious strategies, such as expectancy. Further work by Balota, Black, and Cheney (1992) extended this paradigm and examined presumed deficiencies in expectancy generation among the elderly.

In contrast to the expectancy effect, Neely found evidence for only automatic priming at a shorter SOA (250 ms), regardless of whether the prime–target pairs were expected (e.g., BIRD– *robin*) or unexpected (e.g., BODY– *leg*). Indeed, it is this experiment that is most often cited as evidence that priming at SOAs below 400 ms is purely automatic. However, there are two main problems with this inference. First, Neely's paradigm is inherently difficult, in that people are not accustomed to switching attention to an unrelated category when they encounter a prime. Therefore, his pattern of results at the short SOA could have reflected performance from those (low-AC?) individuals who had difficulty quickly switching attention to an unrelated category. A second, related, problem is that all participants should generate expected targets faster within a category than across categories (Balota et al., 1992). The main point of these problems is that any estimate of a conscious threshold generated from this paradigm is going to be greatly overestimated. Indeed, even in Neely's difficult category-switching paradigm, there is evidence that at least some participants may have been able to generate expectancies within 250 ms. A close inspection of his data at the 250-ms SOA reveals that on average, participants were 20 ms faster to respond to an expected unrelated item (e.g., BODY– *door*) than they were to respond to an unexpected unrelated item (e.g., BODY– *sparrow*). This result is in concurrence with results in the present experiment. An interesting question for future research is the extent to which Neely's data may have been driven by AC. My lab is currently investigating this issue.

A major advantage of the current cued-RP paradigm is that it can be used to examine semantic-priming phenomena previously shown to be modulated by listwide RP. The explicit color-cue procedure could provide evidence as to whether such effects actually depend on listwide context or could instead vary on a trial-by-trial basis. For example, Neely et al. (1989) demonstrated that semantic matching is dependent on a list's nonword ratio. The current design implemented in an LDT would allow for manipulations of nonword ratio, or even separate manipulations of RP and nonword ratio, within a single block of trials, thus unconfounding expectancy and semantic-matching processes. In addition, priming effects are often greater for degraded targets than for clear targets but only under high-RP conditions (Stolz & Neely, 1995). Stolz and Neely argued that a high percentage of valid primes in a list triggers a semantic-feedback process, in which semantic activation from the prime feeds back to activate related items at the lexical and letter levels. This semantic-feedback process was argued to be separate from any expectancy process, as the Degradation × Priming interaction happened even with a 200-ms SOA. Much like Bodner and Masson's (2003) automatic prime-retrieval process, this semantic-feedback hypothesis predicts that the Target Degradation × Priming interaction should be a function of the listwide RP only and should not vary on the color of the prime.

Although many priming effects emerge only when the overall RP is high, other effects emerge solely in low-RP lists. An important example is mediated priming (Balota & Lorch, 1986). Priming from indirectly related items, such as *lion* and *stripes* (via the mediating item *tiger*), is typically eliminated when directly related items are included in a list (Livesay & Burgess, 1998; McKoon & Ratcliff, 1992; McNamara & Altarriba, 1988). Presumably, this occurs because participants begin engaging conscious strategies that work against such mediated effects (the indirectly related item would not be included in the expectancy set, and a matching strategy should bias a nonword response). Because conscious strategies actually reduce mediated priming, Hutchison (2003) argued that such priming is the strongest current evidence for automatic spreading activation. The current color-cue design could provide strong evidence for this assumption, if indeed mediated priming occurred only for low-RP colored primes.

Aging Studies

The current results are in agreement with those of a study by Balota et al. (1992), which examined priming for older adults. Balota et al. used a pronunciation version of Neely's (1977) opposition paradigm and found (Experiment 1) that expectancy-based priming increased for young adults across SOAs of 250, 1,000, and 1,750 ms but decreased for older adults between the middle and longer SOAs. In further experiments, Balota et al. demonstrated that the drop in expectancy-based priming for older adults depended on whether the prime remained on the screen during the interstimulus interval. The dependence of expectancy-based priming on the availability of prime information suggests that the continued presence of the prime may provide external support for the goal of generating expected targets (Craik, 1986). It is likely that without such external support, older adults have difficulty maintaining the expected information in the face of other ongoing distractions. Such an explanation is consistent with models of aging that emphasize deficits in inhibitory control of distracting information (Hasher, Zacks, & May, 1999). Of interest, this age-related inhibitory control model is highly similar to the model of AC presented earlier, in which individual differences in PFC functioning determine the ability to maintain stimulus information over time in the face of distraction (Braver & Cohen, 2000; Kane & Engle, 2002; Norman & Shallice, 1986). Obvious extensions of the current study would involve both testing older adults in this paradigm and examining whether AC differences in RP at the long SOA remain when the prime is visible throughout the interstimulus interval.

Brain Imaging

Much like behavioral measures, previous research with brain imaging has investigated differences in brain activation between related and unrelated trials after onset of the target word. This is because the participant has no way of knowing ahead of time whether a given trial is related or unrelated and thus will engage in the same processes in regard to related and unrelated primes. For example, event-related potential research typically focuses on the N400, which is a negative component of the event-related potential that peaks around 400 ms after word onset and that has previously been demonstrated to reflect semantic processing (Besson, Fischler, Boaz, & Raney, 1992; Deacon, Hewitt, Yang, & Nagata, 2000; Kiefer & Spitzer, 2000; Osterhout & Holcomb, 1995). The fact that the N400 occurs after the onset of the target means that such priming could be due to prelexical processes, such as automatic spreading activation and conscious expectancy, or to postlexical processes, such as strategic semantic matching, automatic semantic integration, or compound cuing. Thus, the N400 (or any other measure of target processing) is no more precise in delineating the underlying priming processes than is a behavioral RT measure.

Brain-imaging studies that have examined differences in brain activation separately across high-versus-low RP lists run into other problems. Most obviously, such studies confound differences in strategic processing across RPs with overall state differences or with general task set across separate blocks of trials. In addition, previous research has demonstrated that automatic processes may contribute to RP effects under such blocked conditions (Bodner & Masson, 2003). Both of these problems render any differences in brain activation across separate blocks of trials difficult or impossible to interpret.

Previous brain-imaging research examining priming under high-RP conditions may be detecting how individuals deal with the consequences of an expectancy-generation process, rather than with the process itself. As a recent example, Gold et al. (2006) demonstrated facilitation effects (related vs. neutral trials) in anterior left inferior PFC but demonstrated inhibition (unrelated vs. neutral trials) in posterior left inferior PFC and bilateral anterior cingulate cortex. Consistent with the interpretation above, they argued that the anterior region is important to strategic retrieval of lexical–semantic information (and thus is less active if the item is already active), whereas the posterior region is critical for selecting the relevant representation from among competitors (and thus is more active following an expectancy set generated from an unrelated prime, in which none of the items match the target). Thus, the current emphasis on inferior PFC, as opposed to dorsolateral PFC, may be a function of the time at which priming effects are measured. It is likely that dorsolateral PFC is most active during the interstimulus interval prior to onset of the target. The current explicit color-cue procedure (Experiment 2) improves on previous imaging designs, because researchers can now measure differences in brain activation both within a block of trials and prior to the onset of the target. Measuring differences in brain activation (in particular, dorsolateral PFC, left inferior PFC, and anterior cingulate cortex) following green versus red primes during the SOA period itself should provide a much more accurate measure of expectancy generation than would either waiting until after target onset or examining differences across separate blocks of trials.

Conclusions

In summary, the current results provide evidence that RP effects can be measured within subjects and within blocks to provide a relatively pure measure of conscious expectancy. Across both experiments, participants were able to use the color of the prime to determine whether to engage in expectancy generation. This process is attentionally demanding, as demonstrated by the dependence of RP effects on individual differences in AC. High-AC participants were better at quickly generating semantic associates and at maintaining them in working memory. These results provide evidence that RP effects from this task can be taken as a signature of conscious expectancy generation. Moreover, this procedure opens the door to numerous potential studies examining semantic-priming phenomena, individual differences in attentional control, and brain imaging.

References

Balota, D. A., Black, S. R., & Cheney, M. (1992). Automatic and attentional priming in young and older adults: Reevaluation of the two-process model. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 485–502.

Balota, D. A., Cortese, M. J., Sergent-Marshall, S. D., Spieler, D. H., & Yap, M. J. (2004). Visual word recognition of single-syllable words. *Journal of Experimental Psychology: General, 133,* 283–316.

Balota, D. A., & Lorch, R. F. (1986). Depth of automatic spreading activation: Mediated priming effects in pronunciation but not in lexical decision. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12,* 336–345.

Balota, D. A., & Yap, M. J. (2006, November). *Effects of semantic priming and stimulus quality: Insights from RT distributional analyses.* Paper presented at the Psychonomic Society conference, Houston, TX.

Becker, C. A. (1980). Semantic context effects in visual word recognition: An analysis of semantic strategies. *Memory & Cognition, 8,* 493–512.

Bengson, J. J., & Hutchison, K. A. (in press). Variability in response criteria affects estimates of conscious identification and unconscious semantic priming. *Consciousness and Cognition.*

Besson, M., Fischler, I., Boaz, T., & Raney, G. (1992). Effects of automatic associative activation on explicit and implicit memory tests. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 89–105.

Bodner, G. E., & Masson, M. E. J. (1997). Masked repetition priming of words and nonwords: Evidence for a nonlexical basis for priming. *Journal of Memory and Language, 37,* 268–293.

Bodner, G. E., & Masson, M. E. J. (2003). Beyond spreading activation: An influence of relatedness proportion on masked semantic priming. *Psychonomic Bulletin & Review, 10,* 645–652.

Braver, T. S., & Cohen, J. D. (2000). On the control of control: The role of dopamine in regulating prefrontal function and working memory. In S. Monsell & J. Driver (Eds.), *Attention and performance XVIII: Control of cognitive processes* (pp. 713–737). Cambridge, MA: MIT Press.

Brown, C. M., Hagoort, P., & Chwilla, D. J. (2000). An event-related potential analysis of visual word priming effects. *Brain and Language, 72,* 158–190.

Bushell, C. M. (1996). Dissociating identity and semantic priming in Broca's aphasia: How controlled processing produces inhibitory semantic priming. *Brain and Language, 55,* 264–288.

Cohen, J., Cohen, P., West, S. G., & Aiken, L. S. (2003). *Applied multiple regression/correlation analysis for the behavioral sciences.* (3rd ed.). Mahwah, NJ: Erlbaum.

Conway, A. R. A., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Oliver, W., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review, 12,* 769–786.

Conway, A. R. A., Kane, M. J., & Engle, R. W. (2003). Working memory capacity and its relation to general intelligence. *Trends in Cognitive Sciences, 7,* 547–552.

Craik, F. I. M. (1986). A functional account of age differences in memory. In F. Klix & H. Hagendorf (Eds.), *Human memory and cognitive capability, mechanisms and performances* (pp. 409–422). Amsterdam: North-Holland/Elsevier.

Deacon, D., Hewitt, S., Yang, C., & Nagata, M. (2000). Event-related potential indices of semantic priming using masked and unmasked words: Evidence that the N400 does not reflect a post-lexical process. *Cognitive Brain Research, 9,* 137–146.

de Groot, A. M. (1984). Primed lexical decision: Combined effects of the proportion of related prime-target pairs and the stimulus-onset asynchrony of prime and target. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 36*A, 253–280.

Den Heyer, K. (1985). On the nature of the proportion effect in semantic priming. *Acta Psychologica, 60,* 25–38.

Den Heyer, K., Briand, K., & Dannenbring, G. L. (1983). Strategic factors in a lexical decision task: Evidence for automatic and attention-driven processes. *Memory & Cognition, 11,* 374–381.

Faust, M. E., Balota, D. A., Spieler, D. H., & Ferraro, F. R. (1999). Individual differences in information-processing rate and amount: Implications for group differences in response latency. *Psychological Bulletin, 125,* 777–799.

Fukushima, J., Fukushima, K., Miyasaka, K., & Yamashita, I. (1994). Voluntary control of saccadic eye movements in patients with frontal cortical lesions and Parkinsonian patients in comparison with that in schizophrenics. *Biological Psychiatry, 36,* 331–349.

Gazzaniga, M. S., Ivry, R. B., & Mangun, G. R. (1998). *Cognitive neuroscience: The biology of the mind.* New York: Norton.

Gold, B. T., Balota, D. A., Jones, S. J., Powell, D. K., Smith, C. D., & Anderson, A. H. (2006). Dissociation of automatic and strategic lexical-semantics: Functional magnetic resonance imaging evidence for differing roles of multiple frontotemporal regions. *Journal of Neuroscience, 26,* 6523–6532.

Hasher, L., & Zacks, R. T. (1979). Automatic and effortful processes in memory. *Journal of Experimental Psychology: General, 108,* 356–388.

Hasher, L., Rose, T., & May, C. P. (1999). Inhibitory control, circadian arousal, and age. In D. Gopher & A. Koriat (Eds.), *Attention and Performance XVII: Cognitive regulation of performance: Interaction of theory and application*, Cambridge, MA: MIT Press.

Henik, A., Friedrich, F. J., Tzelgov, J., & Tramer, S. (1994). Capacity demands of automatic processes in semantic priming. *Memory & Cognition, 22,* 157–168.

Henry, J. D., & Crawford, J. R. (2004). A meta-analytic review of verbal fluency performance following focal cortical lesions. *Neuropsychology, 18,* 284–295.

Hutchison, K. A. (2003). Is semantic priming due to association strength or featural overlap? A micro-analytic review. *Psychonomic Bulletin & Review, 10,* 785–813.

Hutchison, K. A., Balota, D. A., Cortese, M. J., & Watson, J. M. (in press). *Predicting semantic priming at the item level. Quarterly Journal of Experimental Psychology*.

Hutchison, K. A., Neely, J. H., & Johnson, J. D. (2001). With great expectations, can two "wrongs" prime a "right"? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27,* 1451–1463.

Kane, M. J., Bleckley, M. K., Conway, A. R. A., & Engle, R. W. (2001). A controlled-attention view of working memory capacity. *Journal of Experimental Psychology: General, 130,* 169–183.

Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working memory capacity, executive attention, and general fluid intelligence: An individual differences perspective. *Psychonomic Bulletin & Review, 9,* 637–671.

Kane, M. J., & Engle, R. W. (2003). Working-memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to Stroop interference. *Journal of Experimental Psychology: General, 132,* 47–70.

Keefe, D. E., & Neely, J. H. (1990). Semantic priming in the pronunciation task: The role of prospective prime-generated expectancies. *Memory & Cognition, 18,* 289–298.

Kiefer, M., Ahlegian, M., & Spitzer, M. (2005). Working memory capacity, indirect semantic priming, and Stroop interference: Pattern of individual prefrontal performance differences in healthy volunteers. *Neuropsychology, 19,* 332–344.

Kiefer, M., & Spitzer, M. (2000). Time course of conscious and unconscious semantic brain activations. *Neuroreport, 11,* 2401–2407.

Klein, D., Olivier, A., Milner, B., Zatorre, R. J., Johnsrude, I., Meyer, E., & Evans, A. C. (1997). Obligatory role of the LIFG in synonym generation: Evidence from PET and cortical stimulation. *Neuroreport, 85,* 3275–3279.

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

Livesay, K., & Burgess, C. (1998). Mediated priming in high-dimensional semantic space: No effect of direct semantic relationships or co-occurrence. *Brain and Cognition, 37,* 102–105.

MacDonald, A. W., Cohen, J. D., Stenger, V. A., & Carter, C. S. (2000, June 9). Dissociating the role of the dorsolateral prefrontal and anterior cingulate cortex in cognitive control. *Science, 288,* 1835–1838.

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin, 109,* 163–203.

Martin, R. C. (2005). Components of short-term memory and their relation to language processing. Evidence from neuropsychology and neuroimaging. *Current Directions in Psychological Science, 14,* 204–208.

McKoon, G., & Ratcliff, R. (1992). Spreading activation versus compound cue accounts of priming: Mediated priming revisited. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 1155–1172.

McNamara, T. P., & Altarriba, J. (1988). Depth of spreading activation revisited: Semantic mediated priming occurs in lexical decisions. *Journal of Memory and Language, 27,* 545–559.

Meyer, D. E., & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology, 90,* 227–234.

Mummery, C. J., Patterson, K., Hodges, J. R., & Price, C. J. (1998). Functional neuroanatomy of the semantic system: Divisible by what? *Journal of Cognitive Neuroscience, 10,* 766–777.

Mummery, C. J., Shallice, T., & Price, C. J. (1999). Dual-process model in semantic priming: A functional imaging perspective. *Neuroimage, 9,* 516–525.

Neely, J. H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. *Journal of Experimental Psychology: General, 106,* 226–254.

Neely, J. H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. Besner &

G. W.Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp. 264–336). Hillsdale, NJ: Erlbaum.

Neely, J. H., & Keefe, D. E. (1989). Semantic context effects on visual word processing: A hybrid prospective/retrospective processing theory. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 24, pp. 207–248). New York: Academic Press.

Neely, J. H., Keefe, D. E., & Ross, K. L. (1989). Semantic priming in the lexical decision task: Roles of propective prime-generated expectancies and retrospective semantic matching. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 1003–1019.

Norman, D. A., & Shallice, T. (1986). Attention to action: Willed and automatic control of behavior. In R. J. Davidson, G. E. Schwartz, & D. Shapiro (Eds.), *Consciousness and self-regulation: Advances in research and theory* (Vol. 4, pp. 1–18). New York: Plenum.

Osterhout, L., & Holcomb, P. J. (1995). Event-related potentials and language comprehension. In M. D. Rugg & M. G. H. Coles (Eds.), *Electrophysiology of mind: Event-related brain potentials and cognition* (pp. 40–85). Hillsdale, NJ: Erlbaum.

Payne, B. K. (2005). Conceptualizing control in social cognition: How executive functioning modulates the expression of automatic stereotyping. *Journal of Personality and Social Psychology, 89,* 488–503.

Pendleton, M. G., Heaton, R. K., Lehman, R. A., & Hulihan, D. M. (1982). Diagnostic utility of the Thurston word fluency test in neuropsychological evaluations. *Journal of Clinical Neuropsychology, 4,* 307–317.

Perea, M., & Rosa, E. (2002). Does the proportion of associatively related pairs modulate the associative priming effect at very brief stimulus-onset asynchronies? *Acta Psychologica, 110,* 103–124.

Peterson, S. E., Fox, P. T., Posner, M. I., Mintun, M., & Raichle, M. E. (1988, February 18). Positron emission tomographic studies of the cortical anatomy of single-word processing, *Nature, 331,* 585–589.

Posner, M. I., & Snyder, C. R. (1975a). Attention and cognitive control. In R. L. Solso (Ed.), *Information processing and cognition* (pp. 55–85). Hillsdale, NJ: Erlbaum.

Posner, M. I., & Snyder, C. R. (1975b). Facilitation and inhibition in the processing of signals. In P. M. A. Rabbitt & S. Dornic (Eds.), *Attention and performance V.* New York: Academic Press.

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

Rossell, S. L., Bullmore, E. T., Williams, S. C. R., & David, A. S. (2001). Brain activation during automatic and controlled processing of semantic relations: A priming experiment using lexical-decision. *Neuropsychologia, 39,* 1167–1176.

Rossell, S. L., Price, C. J., & Noble, A. C. (2003). The anatomy and time course of semantic priming investigated by fMRI and ERPs. *Neuropsychologia, 41,* 550–564.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime reference guide.* Pittsburgh, PA: Psychology Software Tools.

Seidenberg, M. S., Waters, G. S., Sanders, M., & Langer, P. (1984). Pre- and postlexical loci of contextual effects on word recognition. *Memory & Cognition, 12,* 315–328.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological Review, 84,* 127–190.

Shivde, G., & Thompson-Schill, S. L. (2004). Dissociating semantic and phonological maintenance using fMRI. *Cognitive, Affective, and Behavioral Neuroscience, 4,* 10–19.

Spieler, D. H., & Balota, D. A. (1997). Bringing computational models of word naming down to the item level. *Psychological Science, 8,* 411–416.

Spieler, D. H., Balota, D. A., & Faust, M. (1996). Stroop performance in healthy younger and older adults and in individuals with dementia of the Alzheimer's type. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 461–479.

Stolz, J. A., & Besner, D. (1996). Role of set in visual word recognition: Activation and activation blocking as nonautomatic processes. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 1166–1177.

Stolz, J. A., & Besner, D. (1998). Levels of representation in visual word recognition: A dissociation between morphological and semantic processing. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 1642–1655.

Stolz, J. A., Besner, D., & Carr, T. H. (2005). Implications of measure of reliability for theories of priming: Activity in semantic memory is inherently noisy and uncoordinated. *Visual Cognition, 12,* 284–336.

Stolz, J. A., & Neely, J. H. (1995). When target degradation does and does not enhance context effects in word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 596–611.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18,* 643–662.

Sweeney, J. A., Mintun, M. A., Kwee, S., Wisema, M. B., Brown, D. L., Rosenberg, D. R., & Carl, J. R. (1996). Positron emission tomography study of voluntary saccadic eye movements and spatial working memory. *Journal of Neurophysiology, 75,* 454–468.

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

Tweedy, J. R., Lapinski, R. H., & Schvaneveldt, R. W. (1977). Semantic context effects on word recognition: Influence of varying the proportion of items presented in an appropriate context. *Memory & Cognition, 5,* 84–99.

Van Selst, M., & Jolicoeur, P. (1994). A solution to the effect of sample size on outlier elimination. *Quarterly Journal of Experimental Psychology, 47A,* 631–650.

Vendrell, P., Junque, C., Pujol, J., Jurado, M. A., Molet, J., & Grafman, J. (1995). The role of prefrontal regions in the Stroop task. *Neuropsychologia, 33,* 341–362.

Wagner, A. D., Bunge, S. A., & Badre, D. (2004). Cognitive control, semantic memory, and priming: Contributions from prefrontal cortex. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (3rd ed., pp. 709–725). Cambridge, MA: MIT Press

Whittlesea, B. W., & Jacoby, L. L. (1990). Interaction of prime repetition with visual degradation: Is priming a retrieval phenomenon? *Journal of Memory and Language, 29,* 546–565.

Received July 18, 2006
Revision received January 31, 2007
Accepted February 1, 2007 ■