

Attentional Control and Asymmetric Associative Priming

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Participants completed a battery of 3 attentional control (AC) tasks (OSPAN, antisaccade, and Stroop, as in Hutchison, 2007) and performed a lexical decision task with symmetrically associated (e.g., *sister–brother*) and asymmetrically related primes and targets presented in both the forward (e.g., *atom–bomb*) and backward (e.g., *fire–blaze*) directions at either a 250- or 1,250-ms stimulus onset asynchrony (SOA). As predicted, high-AC individuals showed greater forward priming than low-AC individuals. There was also some evidence that low-AC individuals exhibited greater backward priming than high-AC individuals, and this difference was most pronounced in the later portions of the reaction time distribution. These results suggest that high-AC individuals are more likely to prospectively generate and maintain expected targets in working memory, whereas low-AC individuals are more likely to rely on a retrospective semantic matching or integration processes. These findings support the distinction between proactive and reactive forms of cognitive control embodied in Braver, Gray, and Burgess's (2007) dual-mechanism model of cognitive control.

Keywords: attentional control, semantic priming, asymmetric association

Cognitive control refers to the coordination of attention and memory processes in the service of a goal (Hutchison, Balota, & Duchek, 2010). Recently, Braver, Gray, and Burgess (2007) argued that there are both proactive and reactive forms of cognitive control. Proactive control involves maintaining goal information in an accessible state so as to direct attention toward goal-relevant stimuli and away from potential internal and external distractions. This form of control is effortful, metabolically taxing, and preparatory in nature and uses predictive cues to prepare for a response to an upcoming target. Thus, proactive control corresponds closely to classic conceptualizations of cognitive control as a slow and effortful process (Posner & Snyder, 1975; Shiffrin & Schneider, 1977). In contrast to proactive control, reactive control is a backward-acting process that is automatically triggered by target onset and involves retrieving prior contextual (e.g., goal) information from long-term memory. Use of reactive control does not require continuous effort or monitoring of the environment, but instead involves using a target stimulus to retrieve appropriate actions from long-term memory.

As described by Braver et al. (2007), these two forms of control are revealed within a continuous performance paradigm called the AX-CPT (Braver, Cohen, & Barch, 2002). In the AX-CPT, participants are shown a series of letters and asked to respond to a specific probe letter (X) only when it follows a specific cue letter (A) that with 70% validity cues the occurrence of X on the next trial. Biases to respond to Xs and to make an incorrect “X” response on A + 1 trials are created because the cue A is followed by an X on 70% of the trials. Proactive control in this paradigm involves maintaining the A cue in working memory and using it to maintain an expectancy to make an X response to the following stimulus. This is demonstrated by sustained activity within prefrontal cortex (PFC) during the interval between the cue and probe. In contrast, reactive control involves using the probe (X) to retrieve the preceding cue from memory and is demonstrated by little to no PFC activity during the cue-probe interval combined with longer reaction times (RTs; or increased errors) in rejecting X targets that were preceded by other cues. Across numerous studies, Braver et al. have provided evidence for reduced proactive control among older adults and individuals with schizophrenia, relative to healthy young adults (see Braver et al., 2007, for a review), and increased proactive control among healthy young adults under performance-based reward conditions (Chiew & Braver, 2013).

The distinction between forward-acting and backward-acting control strategies was much earlier also proposed as an explanation for semantic priming effects by Neely and colleagues (Neely, 1977, 1991; Neely, Keefe, & Ross, 1989). Semantic priming is said to occur when individuals respond faster to a target word (e.g., *chair*) that is preceded by a semantically related prime (e.g., *table*) rather than an unrelated prime (e.g., *horse*) and is most commonly measured in lexical (word/nonword) decision and speeded pronunciation tasks. (See McNamara, 2005, for a review.) The proactive (i.e., prospective) strategy in semantic priming is expectancy generation, a process similar to maintaining an expected response in

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the AX-CPT task. Expectancy generation is described by Posner and Snyder (1975) as slow, effortful, and under conscious control and involves using the prime word on a given trial to develop an expectancy for specific related targets during the interval between prime and target onset (i.e., the stimulus onset asynchrony [SOA]). Facilitation in target identification occurs if the target corresponds to an item in the generated expectancy set. However, if the prime and target are unrelated to one another, the time participants spend searching through expected items can potentially hinder the speed of target recognition (see Becker, 1980; Neely, 1991, for more detailed descriptions of expectancy generation).

In contrast to expectancy generation, the reactive (i.e., retrospective) semantic matching process is described as a strategy in which, after semantic information has been activated by the target but before a spelling check has been completed, participants check back to determine whether or not the prime and target are related and use the presence/absence of a relation to bias a word/nonword response, respectively. Similar to reactive control in the AX-CPT, semantic matching requires no maintenance of contextual information during the SOA and instead involves a memory search triggered by target onset. In semantic priming tasks such as lexical decision, semantic matching is effective whenever the presence of a semantic relation is correlated with the appropriate response. Such a correlation usually exists, because nearly all priming studies avoid using nonwords derived from words that are semantically related to their primes (e.g., *boy–girl*). When such a correlation exists, related pairs always require a word response and unrelated pairs usually require a nonword response. Neely et al. (1989) defined this latter contingency, called the *nonword ratio* (NWR), as the proportion of unrelated trials that contain nonword targets. They further noted that the NWR is necessarily confounded with the proportion of prime–target pairs that are related (the so-called relatedness proportion [RP]) in a lexical decision task whenever the ratio of word to nonword targets is held constant across changes in RP, as had always been the case.

Contrary to Braver et al.'s (2007) claim that reactive control is automatically triggered, retrospective semantic matching has traditionally been described as a strategic process (e.g., Thomas, Neely, & O'Connor, 2012) because its use is modulated by the NWR (Neely, Keefe, & Ross, 1989). However, no studies have examined whether semantic matching actually requires effort or can be consciously controlled, whereas many studies have demonstrated that expectancy generation can be consciously controlled (Balota, Black, & Cheney, 1992; Favreau & Segalowitz, 1982; Hutchison, 2007; Neely, 1977). In addition, participants do not report experiencing any conscious decision to use a semantic-matching strategy when performing a lexical decision task. Thus, it is indeed possible that the process of semantic matching is automatically triggered by target onset when target–prime relatedness predicts the appropriate response.

There is ample evidence for both expectancy generation and semantic-matching processes. Evidence for expectancy generation comes from studies showing that semantic priming increases as RP increases (the RP effect), but only if the SOA is long enough to allow individuals time to generate expected targets (de Groot, 1984; Den Heyer, 1985; Den Heyer, Briand, & Dannenbring, 1983; Hutchison, Neely, & Johnson, 2001; Neely, 1977; Stolz & Neely, 1995). This evidence conforms to Braver et al.'s (2007) notion that proactive processes require predictive environmental

cues. More recently, Hutchison (2007) examined RP effects in pronunciation by using primes having different font colors to indicate that the upcoming target would be related to the prime either 80% or 20% of the time. This allowed random trial-by-trial cuing of RP, while maintaining the overall RP at 50%. To validate that controlled expectancy produced the increased priming observed when the prime's font color cued a high RP, Hutchison included a battery of three tasks that measure individual differences in the ability to control attention (Operation Span [OSPA], Stroop, and antisaccade). Hutchison found that for high- "attentional control" (AC) individuals, priming was greater when the font color cued a high RP at both a 267-ms and 1,240-ms SOA. This suggests that they could quickly generate an expectancy for related targets and maintain them in working memory. However, low-AC individuals did not show this increase in priming at either SOA, suggesting that they could not quickly generate an expectancy at the 267-ms SOA and either did not generate an expectancy at all or failed to maintain an expectancy they did generate for 1,240 ms.

Evidence for retrospective semantic matching comes from studies using prime–target pairs with an asymmetric association (see Hutchison, 2003, for a review). For instance, in word association tasks in which participants are asked to give the first word to come to mind when given a cue, the cue *stork* often elicits the response *baby*; however, the cue *baby* never elicits the response *stork*. Lexical decisions typically show priming for prime–target pairs presented in the backward direction (e.g., *baby–stork*) that is equal to priming for pairs presented in the forward direction (e.g., *stork–baby*) (see Hutchison, 2003). This is consistent with the idea that backward priming in lexical decision is due to a retrospective semantic-matching process occurring after the target word is accessed.

Balota and colleagues (Balota, Yap, Cortese, & Watson, 2008; Yap, Balota, & Tan, 2013; see also Whittlesea & Jacoby, 1990) have provided evidence that participants may be more likely to retrieve contextual information from memory under conditions in which bottom-up target processing is impaired (e.g., degraded targets). Rather than focusing only on mean priming effects, they examined the entire RT distributions for related and unrelated trials to assess whether priming exerts its influence equally throughout the entire distribution or instead primarily affects only the longest RTs. At longer SOAs, they found that priming effects for clearly presented targets reflected an overall shift in the RT distribution; however, priming effects for visually degraded targets were skewed, such that they increased toward the upper tail of the RT distribution. Balota et al. interpreted this different priming pattern for nondegraded and degraded targets as reflecting a greater use of retrospective retrieval processes for degraded targets, because retrospective retrieval cannot be initiated before the target appears.

Consistent with this memory retrieval interpretation, Thomas et al. (2012) recently demonstrated that enhanced priming for degraded targets, relative to nondegraded targets, occurs when prime–target pairs have an asymmetric backward association, but not when they have an asymmetric forward association. Thomas et al. argued that this finding suggests enhanced priming for degraded targets is produced solely by a retrospective semantic processing mechanism that operates only if a backward target-to-prime association is present. Thomas et al. further demonstrated that their

Target Degradation \times Priming interaction was not caused solely by slowed processing time for degraded targets, because significantly increased priming for degraded targets was still observed across RT bins for which RTs in the unrelated priming condition were matched with those for clear targets. This means that for those bins, RTs in the related priming condition were faster for degraded than nondegraded targets! This strongly suggests that retrospective semantic matching was more likely to be engaged for degraded than for nondegraded targets, thereby reversing the effect of degradation. Thus, the increase in the Priming \times Target Degradation interaction that occurred in Thomas et al.'s later RT bins for their backward-associated and symmetrically associated pairs is consistent with Balota et al.'s (2008) claim that this interaction is mediated by a retrospective, retrieval-based mechanism. Taken together, these results suggest that retrospective semantic matching can serve as a compensatory process (see Stanovich & West, 1983) that increases priming when bottom-up processing is impaired.

The Present Experiment

In the present experiment, we used Hutchison's (2007) AC battery to examine individual differences in priming for forward associates (FA; e.g., *atom–bomb*) and backward associates (BA, e.g., *fire–blaze*), as well as symmetric associates (SYM; e.g., *brother–sister*) in which the association strength is equal in both directions. We predict that AC will positively correlate with the proactive process of expectancy generation, because one must generate and maintain possible target items in working memory during the blank interval between prime and target. This prediction is consistent with Braver et al.'s (2007) claim that individuals high in working memory capacity are more likely to use proactive strategies and Hutchison's (2007) finding that in a pronunciation task, only high-AC individuals demonstrated RP effects, which are presumably mediated by prospective expectancies. As in Hutchison (2007), both a short (250-ms) and long (1,250-ms) SOA were used to examine potential individual differences in quick generation versus prolonged maintenance of expected targets. Classic models of expectancy generation (e.g., Neely, 1977; Posner & Snyder, 1975) would predict that expectancy-based priming would only emerge at the longer SOA. However, as mentioned earlier, Hutchison (2007) found that AC differences in RP effects were equal at short and long SOAs. Therefore, it is predicted that AC differences in forward priming will not differ across SOA, suggesting that high-AC individuals are more likely to engage in expectancy and can do so rapidly. In contrast, because semantic matching is presumably an automatic process triggered by target onset and does not require continual effort, we predict that both high- and low-AC individuals should demonstrate backward priming. Moreover, Neely (1991) has argued for greater semantic matching at longer SOAs due to a more strongly encoded semantic representation of the prime. Thus, we predict greater backward priming at the long SOA. Finally, if semantic matching serves as a compensatory process for deficient proactive control, low-AC individuals might show greater BA priming than high-AC individuals, and this too should be greater at the long SOA. Thus, whereas high-AC individuals should show enhanced FA priming relative to low-AC individuals, low-AC individuals may or may not show enhanced BA priming relative to high-AC individuals. The predicted difference for SYM priming as a function of AC is not

clear-cut, because SYM priming can be influenced by either expectancy generation or semantic matching. Given the different predicted time courses of expectancy generation and semantic matching, however, it may tentatively be predicted that a high-AC advantage in forward priming may emerge at the early SOA and remain (replicating Hutchison's RP effect pattern), whereas a low-AC advantage in backward priming, if present, should emerge relatively late. Similarly, when testing RT distributions, a high-AC advantage should emerge early in the distribution (due to expectancy producing a "head start" in target processing) and remain, whereas a low-AC advantage in BA priming, if present, should emerge in later bins (indicative of retrospective prime retrieval; see Balota et al., 2008).

Method

Participants

Two hundred thirty-seven native English-speaking male and female students from Montana State University ($n = 176$) and the State University of New York at Albany ($n = 61$) participated. They completed the study for partial completion of a requirement for an introductory psychology course. Data from eight participants were not analyzed due to failure to complete all four required tasks. In addition, data were not analyzed from seven participants who made more than 15% math errors on the OSPAN task and six participants who made more than 40% errors in any condition in the lexical decision task. Thus, data from 216 participants were analyzed.

Design

The experiment was a mixed-factor design with SOA (250 ms and 1,250 ms), relatedness (related and unrelated), and type of association (FA, BA, and SYM) manipulated within-subjects and AC measured continuously between subjects. SOA was manipulated across blocks, whereas relatedness and type of association varied randomly from trial to trial. The main dependent variables in the priming task were RT and error rates.

Priming Task

Stimuli. The critical priming stimuli were 40 FA (e.g., *atom–bomb*), 40 BA (e.g., *fire–blaze*), and 40 SYM (e.g., *brother–sister*) prime–target pairs taken from Thomas et al. (2012). The targets for the three different type of association conditions were different because it would be virtually impossible to hold the target constant and find three different primes for each target that would equate forward and backward associative strengths across the three type of association conditions. We chose 120 of Thomas et al.'s 180 items in order to better match the SYM items to the FA and BA pairs in forward and backward associative strength, respectively, and to match all three types of targets in lexical decision RTs according to the English Lexicon Project (ELP) database (Balota et al., 2007). Lexical and semantic attributes for the present items are shown in Table 1. The mean forward prime-to-target association strengths were .55 for FA, .00 for BA, and .56 for SYM pairs. The mean backward prime-to-target association strengths were .00 for FA, .56 for BA, and .59 for SYM. The mean (unprimed) ELP

Table 1
Mean Values of Lexical and Semantic Attributes of the Prime and Target Stimuli as a Function of Prime-to-Target Associative Direction

Item attribute	BA	FA	SYM	F or t	p
Target length	5.4	5.4	5.3	0.08	.92
Target frequency (logged HAL) [#]	3.9	4.2	4.1	2.67	.07
Target semantic set size [^]	9.55 ^a	14.43 ^b	9.30 ^a	20.35 [*]	.00
Target mean connectivity among associates [^]	1.22 ^a	1.72 ^b	1.44 ^{a,b}	4.79 [*]	.01
Target-normed LDT RT (in ms) [#]	617	617	617	0.00	.99
Target-normed LDT Acc (in %) [#]	.97	.98	.97	1.84	.16
Target orthographic neighborhood size [#]	3.8	4.2	4.3	0.14	.87
Prime-to-target association strength [^]	0.0	.55	.55	0.21	.84
Target-to-prime association strength [^]	.56	0.0	.59	0.99	.32

Note. Semantic set size is defined as the number of different responses generated by two or more participants. Mean connectivity was computed by counting the number of connections among associates and dividing by the size of the set. The associates used in this computation were generated by a different group of participants. The *F* values in the first seven rows of the *F* or *t* column are values generated from one-way analyses of variance (ANOVAs) using Associative Direction as a fixed factor; the *t* values in the last two rows were generated from independent samples *t* tests between the two item types that were matched for either forward or backward strength, respectively. Post hoc Bonferroni-adjusted contrasts were conducted if the one-way ANOVA was significant. For superscripts within each row, the numerically lowest mean is always assigned *a*, and means with superscripts that do not share letters are significantly different ($p < .05$). BA = backward associates; FA = forward associates; SYM = symmetric associates; LDT = lexical decision task; RT = reaction time; Acc = percent accuracy.

[#] Retrieved from Balota et al. (2007). * *F* or *t* value is significant at $p < .05$. [^] Retrieved from Nelson, McEvoy, and Schreiber (1999).

lexical decision RTs were all 617 ms for the FA, BA, and SYM targets. Comparing our Table 1 stimulus characteristic data with the corresponding data for Thomas et al.'s larger set of items shows that our smaller set is indeed better matched. Thomas et al.'s SYM pairs had significantly stronger backward target-to-prime associations than their BA pairs, $t(118) = 3.07$, $SE = .02$, whereas our conditions did not differ, $t(78) = 0.99$, $SE = .02$. Additionally, the Thomas et al. items significantly differed in logged HAL target frequency, $F(2, 179) = 3.50$, $MSE = .38$, whereas this difference was marginally significant ($p = .074$) for the present items, $F(2, 117) = 2.67$, $MSE = .43$. Within each of the BA, FA, and SYM pairs, related pairs were scrambled to create unrelated pairs. Due to a programming error, the SYM target *supper* was preceded by the prime *dinner* in both "related" and "unrelated" conditions. (This error also occurred but went undetected for the Thomas et al. experiment.) This pair was therefore removed from the data prior to any analyses.

In addition to the critical stimuli, we used 200 of Thomas et al.'s (2012) noncritical SYM stimuli as filler related prime-word target trials (80 pairs) and to create word-prime/nonword target trials (120 pairs). As described in Thomas et al., one or two interior letters from SYM targets were replaced to create pronounceable nonword targets for the nonword target trials, and the pairs were rescrambled such that none of the primes and nonword targets were "related." Because related BA pairs do not count toward RP and related FA pairs do not count toward NWR (see Footnote 1 in Thomas et al. for explanations), our overall RP and NWR were .60. These values were the same as in Thomas et al.¹ Eight lists were created to counterbalance critical word pairs across SOA (250 or 1,250 ms), SOA order (250-ms block first or 1,250-ms block first), and relatedness conditions.

Procedure. Individually tested participants seated approximately 60 cm away from a video graphics array (VGA) monitor

were told that they would see an uppercase word followed by a lowercase target letter string. They were instructed to read the uppercase word silently and make a lexical decision to the target as quickly as possible by pressing the "/" key marked "word" or the *z* key marked "nonword." All stimuli were centered on the VGA screen and presented using E-prime software (Schneider, Eschman, & Zuccolotto, 2002). Each trial began with a 600-ms fixation (+), followed by a 150-ms prime display. A blank screen was then presented for either 100 ms or 1,100 ms, creating an SOA of either 250 ms or 1,250 ms. SOA was blocked such that participants received either the short or long SOA in Block 1, followed by the opposite SOA in Block 2, with blocks counterbalanced across participants. The target was then displayed for 6,000 ms or until a response was given. The intertrial interval was 2,000 ms, which should have kept overall cognitive load low enough that participants would have the attentional resources necessary to generate an expectancy (Neely, O'Connor, & Calabrese, 2010). Self-paced rest breaks were given every 50 trials. Each SOA block was preceded by eight randomly presented practice trials that contained four nonword-target and four word-target SYM pairs. Half of the word targets were related to their primes. Each prime and target appeared only once in the experiment.

AC Battery

The AC battery consisted of the OSPAN, antisaccade, and Stroop tasks used (and described in detail) in Hutchison (2007,

¹ Thomas et al. (2012) reported an NWR of .67. The correct calculation should have been $180 \text{ NW} / (180 \text{ NW} + 30 \text{ SYM unrelated} + 30 \text{ BA unrelated} + 30 \text{ FA unrelated} + 30 \text{ FA related}) = .60$. This error was due to forgetting to count the 30 FA-related pairs as unrelated.

Experiment 2). These tasks were given prior to the priming task for half the participants and after the priming task for the other half. Because presentation order of the AC battery and priming task did not interact with any other variables in the analysis, the data are collapsed across this factor. The entire session lasted approximately 1 hr.

Preliminary Data Analysis

Data scoring. Only correct responses were included in all RT analyses. Because RT distributions tend to be positively skewed, outliers in the lexical decision and Stroop tasks were removed per Van Selst and Jolicoeur's (1994) nonrecursive procedure. It removed 2.3% and 2.5% of the correct RTs in the priming and Stroop tasks, respectively. Semantic priming was computed by subtracting mean RT and error rates in the related condition from the means in the unrelated condition. Stroop interference effects were computed by subtracting the mean RT or percent error for congruent words from the means for incongruent words. Performance in the OSPAN and antisaccade tasks was scored as in Hutchison (2007) and could range from 0 to 50 and from 0 to 1 (.50 equals chance performance), respectively.

Principal components analysis (PCA). Each task likely contains variability due not only to AC but also to task-specific abilities. As a result, common variance among the tasks should more accurately reflect one's degree of AC than performance on any one task alone. A component hypothesized to reflect AC should receive positive loadings for antisaccade and OSPAN measures and negative loadings for Stroop.

Results

AC Battery

Table 2 displays descriptive statistics for each task and includes measures of internal consistency for these tasks as reported by Hutchison (2007). Table 3 shows intercorrelations between tasks and individual task loadings on the PCA. Stroop RT and error effects were each transformed to z scores and then averaged for each participant to derive an overall Stroop effect. This was done to prevent the Stroop task from artificially loading more strongly on the PCA simply due to having two intercorrelated measures. As shown in Table 3, the PCA loading replicated the pattern found in

Table 2
Descriptive Statistics for the AC Battery

Task	<i>M</i>	<i>SD</i>	Range	Internal consistency
OSPAN	8.06	5.79	0–27	.701 ^a
Antisaccade	0.71	0.14	.39–1.00	.691 ^b
Stroop RT	117.58	63.20	–17–341	.677 ^b
Stroop error	6.23	6.96	–6.0–61.0	.676 ^b

Note. AC = attentional control. OSPAN refers to the Operation Span task. Antisaccade refers to performance in the antisaccade task. Stroop RT and Stroop error refer to reaction time and percent error differences between incongruent and congruent conditions.

^a Reported in Conway et al. (2005). ^b Reported in Hutchison (2007, Experiment 2).

Table 3
Intercorrelations Among AC Battery Tasks and Principal Component Analysis (PCA) Unrotated Matrix

Variable	OSPAN	Antisaccade	Stroop	PCA loading
OSPAN	—	.22*	–.21*	+ .69
Antisaccade		—	–.21*	+ .69
Stroop			—	–.69

Note. AC = attentional control; OSPAN = Operation Span task.

Hutchison (2007), with OSPAN and antisaccade loading positively and Stroop loading negatively. The similar intercorrelations between tasks led to equal component weightings for each task. As is typical with this battery, there was only one significant component (Hutchison, 2007) that explained 48% of the variance in performance across tasks. Individual scores on this AC component ranged from –3.74 to +2.66.²

Semantic Priming Task

RTs were first analyzed using the general linear model with SOA, type of association, and relatedness as within-subject factors. Overall priming effects in RT, z scores, and errors were tested both by subjects and by items. In a second analysis, AC was included in the model and treated as a continuous between-subject variable so as to increase power and reduce spurious effects (Cohen, Cohen, West, & Aiken, 2003). Item analyses were not conducted when AC was included as a variable because item analyses require collapsing across subjects. For all analyses, trimmed scores are reported, but data were also analyzed with z scores so as to reduce spurious interactions caused by individual differences in baseline RT (see Faust, Balota, Spieler, & Ferraro, 1999; Hutchison, Balota, Cortese, & Watson, 2008). Thus, separately for each SOA, we computed each participant's grand mean and the standard deviation for all trimmed RTs for correct responses to the 120 critical targets and then computed a z score for each of those RTs. Unless otherwise noted, all reported RT effects were confirmed by the z -score analysis. All reported significant effects are associated with $p < .05$, and all reported p values are two-tailed.

Table 4 presents the mean RT and error data from all participants as a function of SOA, type of association, and relatedness. Averaged across SOA, semantic priming occurred and was greater for SYM (53 ± 12 ms) and BA (49 ± 11 ms) pairs than for FA (27 ± 10 ms) pairs ($\pm = 95\%$ CI). These observations were confirmed by a main effect of relatedness, $F_s(1, 215) = 149.07$, $MSE = 7,936$, $\eta_p^2 = .41$; $F_i(1, 116) = 142.34$, $MSE = 2,162$, $\eta_p^2 = .55$, and a Relatedness \times Type of Association interaction, $F_s(2, 430) = 6.51$, $MSE = 6,399$, $\eta_p^2 = .03$; $F_i(2, 116) = 3.27$, $MSE = 2,162$, $\eta_p^2 = .05$. It is of interest that BA priming in the present study was greater than FA priming and equal to SYM priming. The greater

² The low intercorrelations between AC tasks presents a concern for interpreting the extracted PCA component argued to reflect shared variance across tasks. However, because this pattern has now been replicated across eight experiments in the first author's lab, we are confident in the stability of the obtained pattern. Also, principal axis factoring showed lower factor loadings overall, but did not change the obtained pattern (OSPAN = +.46, antisaccade = +.47, Stroop = –.46).

Table 4
Mean Reaction Time (RT) and Percentage of Error for the Priming Task for Related and Unrelated FA, BA, and SYM Pairs and Nonwords as a Function of SOA

Variable	SOA			
	250 ms		1,250 ms	
	<i>M</i>	% err	<i>M</i>	% err
Nonwords	868 (16)	10.6 (0.6)	906 (17)	8.0 (0.5)
FA pairs				
Unrelated	661 (12)	1.5 (0.3)	729 (14)	2.3 (0.4)
Related	640 (12)	1.3 (0.3)	696 (14)	1.0 (0.2)
Priming	+21* (6)	+0.2 (0.4)	+33* (8)	+1.3* (0.4)
BA pairs				
Unrelated	753 (14)	7.7 (0.7)	811 (16)	7.6 (0.7)
Related	697 (13)	4.7 (0.5)	769 (15)	4.2 (0.5)
Priming	+56* (8)	+3.0* (0.8)	+42* (8)	+3.4* (0.9)
SYM pairs				
Unrelated	696 (13)	3.2 (0.5)	766 (15)	4.0 (0.5)
Related	643 (11)	2.3 (0.3)	713 (15)	1.7 (0.3)
Priming	+53* (7)	+0.9* (0.5)	+53* (9)	+2.3* (0.5)

Note. FA = forward associates; BA = backward associates; SYM = symmetric associates; SOA = stimulus onset asynchrony. Standard error appears in parentheses. Bold font indicates unrelated–related conditions. $\diamond p < .10$. * $p < .05$.

BA than FA priming in the present study differs from past results that have generally shown FA and BA priming to be equal (Kahan et al., 1999; Koriat, 1981).³

There was also a main effect of SOA, with 66 ± 15 -ms slower RTs at the longer SOA, $F_3(1, 215) = 77.31$, $MSE = 36,333$, $\eta_p^2 = .26$; $F_1(1, 116) = 312.65$, $MSE = 1,490$, $\eta_p^2 = .73$. This could be indicative of a loss of vigilance during the delay. When data were collapsed across type of association, semantic priming did not differ across SOAs, as indicated by a null Relatedness \times SOA interaction ($F < 1$, $\eta_p^2 < .001$). This null interaction is consistent with several past studies (e.g., Hutchison et al., 2001; Kahan, Neely, & Forsythe, 1999). However, as can be seen in Table 4, this null Priming \times SOA interaction may be misleading because FA and BA priming patterns across SOA were opposite. When only the FA and BA pairs were included in the analysis, there was an SOA \times Type of Association \times Relatedness interaction in trimmed RTs that was significant by items, $F_1(1, 78) = 8.64$, $MSE = 1,173$, $\eta_p^2 = .10$, and marginally significant ($p < .065$) by subjects, $F_8(1, 215) = 3.43$, $MSE = 5,327$, $\eta_p^2 = .02$. For z scores, this interaction was significant by both subjects and items, $F_8(1, 215) = 5.88$, $MSE = .12$, $\eta_p^2 = .03$; $F_8(1, 78) = 10.83$, $MSE = .02$, $\eta_p^2 = .12$.⁴ Separate contrasts showed that priming for FA pairs numerically increased by 12 ± 18 ms across SOA, whereas priming for BA pairs numerically decreased by 14 ± 22 ms across SOA. For FA pairs, the increase in priming across SOA was significant by items, $t_1(39) = 2.72$, $\eta_p^2 = .16$, but not by subjects, $t_5(215) = 1.29$, $\eta_p^2 = .01$. For BA pairs, the decrease in priming across SOA was significant by both subjects and items in the z -score analysis, $t_5(215) = 2.14$, $\eta_p^2 = .02$; $t_1(39) = 2.17$, $\eta_p^2 = .04$, but not in the trimmed RT analysis, $t_5(215) = 1.30$, $\eta_p^2 = .01$; $t_1(39) = 1.49$, $\eta_p^2 = .05$. As noted by Kahan et al. (1999, p. 109), if it is assumed that BA priming is caused solely by a semantic-matching process, then this finding of greater BA priming at a short SOA is evidence refuting Neely's (1991) claim that semantic matching requires longer SOAs to

be implemented because it depends on extraction of complete semantic information from the prime.

In the general linear model that included AC, there was no overall effect of AC, $F(1, 214) = 0$, $MSE = 371,373$, $\eta_p^2 = .00$. However, there was an SOA \times AC interaction, $F(1, 214) = 4.70$, $MSE = 35,717$, $\eta_p^2 = .02$, such that the change in RT as SOA increased was negatively correlated with AC, $r(214) = -.147$, $p = .031$. This difference might reflect a general lapse in attention (mind wandering) during the delay for low-AC individuals (cf. McVay & Kane, 2009). This is also consistent with the hypothesis that low-AC individuals rely on reactive control processes rather than actively maintaining expected targets during the delay between prime and target. Of most importance, and as predicted, an AC \times Type of Association \times Relatedness crossover interaction occurred that was significant in the z -score analysis, $F(2, 428) = 4.01$, $MSE = .13$, $\eta_p^2 = .02$, and marginally significant in the trimmed RT analysis, $F(2, 248) = 2.83$, $p = .06$, $\eta_p^2 = .01$, indicating that the patterns of priming for FA, BA, and SYM pairs depended on AC.

³ The greater BA than FA priming observed here contrasts with Thomas et al.'s data (2012), which showed equal FA and BA priming and priming for SYM pairs to be statistically equivalent to the sum of FA and BA priming for their clearly visible targets. In the present study, BA priming exceeded FA priming, and the 53-ms SYM priming effect was 23 ± 18 ms smaller than the 76 ± 8 -ms sum of the 27 ± 10 -ms FA and 49 ± 11 -ms BA priming effects, which represents a significant underadditive pattern of priming, $t(215) = 2.54$, $\eta_p^2 = .03$. However, their and our results are actually similar. Thomas et al.'s additivity claim for their clear targets in their lexical decision task was based on their 52-ms SYM priming effect not being significantly different (two-tailed) from the 62-ms sum of FA (32 ms) and BA (30 ms) priming. Although our 23 ± 18 -ms underadditive effect is significantly different from zero, it is not significantly different from Thomas et al.'s 10 ± 15.5 -ms underadditive effect, $t(382) = .75$, $p = .23$. When the data from the present experiment and Thomas et al. are combined, the (weighted-mean) 17 ms of underadditivity remains significant by Winer's (1971, pp. 49–50) z test ($z = 2.68$, $p < .01$). Winer's $z = \sum t_j / \sqrt{(\sum f_j / (f_j - 2))}$, where t_j is the obtained t value for the effect of interest, and f_j is the degrees of freedom associated with t_j . (The t value of 1.27 for Thomas et al.'s, 2012, underadditive effect was obtained by taking the square root of its associated F value.) Moreover, an analysis of the error rates reveals almost identical underadditive patterns in both studies. In the present study, we found 2.4% underadditivity in error priming (1.6% for SYM, 0.7% for FA, and 3.2% for BA), and Thomas et al. found 2.6% underadditive error priming (1.7% for SYM, 0.7% for FA, and 3.6% for BA). Finally, Thomas et al. (2012) also found a small 5 ± 13.87 -ms underadditive effect for their degraded targets in their lexical decision task—75 ms of SYM priming versus an 80-ms sum of FA (36 ms) and BA (44 ms) priming. Even when this small underadditive effect is combined with the present 23 ms of underadditivity and Thomas et al.'s 10 ms of underadditivity, the (weighted-mean) 13.5 ms of underadditivity remains significant by Winer's z test ($z = 2.60$, $p < .01$). In summary, it is clear that when considered together, the results of the present study and Thomas et al. (2012) converge to indicate that BA and FA priming show underadditivity for both RTs and errors when the two types of priming are united in SYM pairs. This strongly undermines the claim that prospective and retrospective priming mechanisms independently influence priming and suggests that prospective and retrospective mechanisms interact such that the use of one diminishes the use of the other.

⁴ When symmetrical pairs were included in the analysis, the SOA \times Type of Associate \times Relatedness interaction was still significant for the z -score analysis, $F_3(2, 428) = 3.32$, $MSE = .112$, $\eta_p^2 = .02$; $F_1(2, 116) = 4.99$, $MSE = .03$, $\eta_p^2 = .08$. However, for the trimmed means, the interaction was significant by items, $F_1(2, 116) = 4.36$, $MSE = 1,165$, $\eta_p^2 = .07$, but not by subjects, $F(2, 428) = 1.88$, $p = .16$, $\eta_p^2 = .01$.

When SYM pairs were excluded to examine the pure effects of FA and BA priming, the AC \times Type of Association \times Relatedness crossover interaction became significant for both the trimmed and z -score analyses, $F(1, 214) = 5.76$, $MSE = 6,206$, $\eta_p^2 = .03$; $F(1, 214) = 7.92$, $MSE = .13$, $\eta_p^2 = .04$, respectively. Figure 1 illustrates the relation between AC and priming for FA, BA, and SYM pairs for z scores so as to avoid noise due to differences with baseline RTs. As shown in Figure 1, as AC increased, FA priming increased, whereas priming for BA decreased. Post hoc correlations showed that the increase in FA priming across AC was significant, $r(214) = .18$, $p = .007$, whereas the decrease in BA priming was not, $r(214) = -.082$, $p = .229$. SYM priming was relatively stable across AC, $r(214) = .070$, $p = .304$, as might be anticipated from the opposite-signed correlations for FA and BA priming. This pattern did not differ across SOAs, as demonstrated by the null four-way interaction that included SOA ($F < 1$, $\eta_p^2 < .001$). No other significant effects were found. Given that priming effects themselves often show reliabilities not much greater than .30 (Hutchison et al., 2008; Stolz, Besner, & Carr, 2005), the $+.18$ correlation obtained for FA priming shows that AC captured a substantial amount of the explainable (i.e., predictable) variability in FA priming across participants. Interestingly, the present $+.18$ correlation between AC and FA priming was almost identical to the $+.19$ and $+.18$ correlations between AC and RP effects obtained by Hutchison (2007) in Experiments 1 and 2, respectively.

For errors, a significant semantic priming effect was found, $F(1, 214) = 51.54$, $MSE = 43$, $\eta_p^2 = .19$, as was a Type of Association \times Relatedness interaction, $F(2, 430) = 10.27$, $MSE = 34$, $\eta_p^2 = .05$. Although all three priming effects were significant (see Table 4), pairwise comparisons revealed that priming was greater for BA pairs ($3.2 \pm 1.1\%$) than SYM pairs ($1.6 \pm 0.7\%$), and was lowest for FA pairs ($0.7 \pm 0.5\%$). Thus, priming in errors replicated the underadditive effect found for RTs. Although there was no main effect of SOA on error rates ($F < 1$), there was an SOA \times Relatedness interaction, $F(1, 214) = 5.83$, $MSE = 37$, $\eta_p^2 = .02$, in which priming effects increased by $1.0 \pm 0.9\%$ from the 250-ms

to 1,250-ms SOA. There was also an SOA \times AC interaction, $F(2, 214) = 6.08$, $MSE = 37$, $\eta_p^2 = .03$. As was so for the RT data, increases in error rates across SOA were negatively related to AC, $r(214) = -.16$, $p = .017$. No other effects were significant.

Additional mixed-factor analyses of variance (ANOVAs) examined effects of SOA and AC on nonword RTs and error rates. As was so for word RTs, nonword RTs were 38 ± 22 ms slower at the long SOA, $F(1, 215) = 11.86$, $MSE = 12,908$, $\eta_p^2 = .05$. No other effects were significant. Nonword errors were negatively related to AC, $r(214) = -.278$, $p = .000$, and participants made $2.6 \pm 1.0\%$ fewer errors at the long SOA ($7.9 \pm 0.5\%$) than at the short SOA ($10.6 \pm 0.6\%$). These observations were confirmed by main effects of AC, $F(1, 215) = 17.88$, $MSE = 102$, $\eta_p^2 = .08$, and SOA, $F(1, 215) = 27.06$, $MSE = 28$, $\eta_p^2 = .11$. However, these variables did not interact ($F < 1$, $\eta_p^2 < .001$), and no other interactions were significant.

Distributional analyses. In our final analysis, we examined the RT distributional data. As discussed in the introduction, increases in priming for longer RTs are generally considered to reflect retrospective processes such as semantic matching, whereas overall shifts in the distribution are more indicative of prelexical priming mechanisms (Balota et al., 2008; Thomas et al., 2012). Thus, the advantage for high-AC individuals in FA priming should begin early, whereas any potential advantage for low-AC individuals in BA priming should begin late. We estimated the following quantiles (.125, .275, .425, .575, .725, and .875) for each participant, as a function of condition. The quantiles were then averaged across participants to yield the quantile plots presented in Figure 2. Because participants in the present study had only 10 observations per SOA \times Type of Association \times Relatedness condition, we collapsed across SOA in creating quantile estimates. The number of valid observations in each bin (excluding errors and outliers) ranged from 12 to 20 ($M = 19.2$). Distributional FA, BA, and SYM priming effects are shown in Figure 2. Because no predictions were made for medium-AC individuals, the analysis only examined high- versus low-AC groups. These groups were identified using the top 25% and bottom 25% of the AC distribution. To examine the time course of AC differences, we combined the first two and last two quantiles to create early and late-RT bins. We predicted that the high-AC advantage in FA priming should appear early in the distribution, whereas any low-AC advantage in BA priming, if obtained, should occur only in late bins.

An ANOVA was first conducted investigating RT bin (early vs. late) and AC group (high vs. low) for SYM priming. SYM priming did not differ between high- and low-AC participants ($F < 1$, $\eta_p^2 = .00$). SYM priming was greater in the later portion of the distribution, $F(1, 107) = 4.98$, $MSE = 19,487$, $\eta_p^2 = .04$. Specifically, SYM priming was 42 ± 38 ms greater in the late bin (92 ± 38 ms) than in the early bin (50 ± 10 ms), $F(1, 107) = 4.98$, $MSE = 19,487$, $\eta_p^2 = .04$. The AC \times RT Bin interaction was not significant ($F < 1$, $\eta_p^2 = .00$).

To test for predicted differences in FA and BA priming patterns, an AC Group \times Type of Association (FA vs. BA) \times RT Bin ANOVA was conducted on the FA and BA priming effects. The main effect of AC group was not significant, $F(1, 107) = .32$, $MSE = 16,774$, $\eta_p^2 = .00$, but the main effect of RT bin was, $F(1, 107) = 15.94$, $MSE = 13,195$, $\eta_p^2 = .13$, with 44 ± 22 ms more priming in the late bin than in the early bin, averaged over FA and BA priming. Of most importance, there was a marginally signifi-

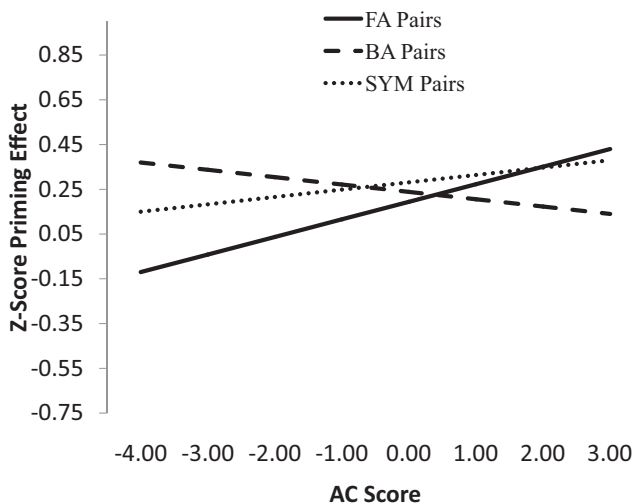


Figure 1. Best fitting regression lines predicting z -score priming effects as a function of AC. As AC increased, FA priming also increased. BA and SYM priming were not statistically correlated with AC. FA = forward associates; BA = backward associates; SYM = symmetric associates; AC = attentional control.

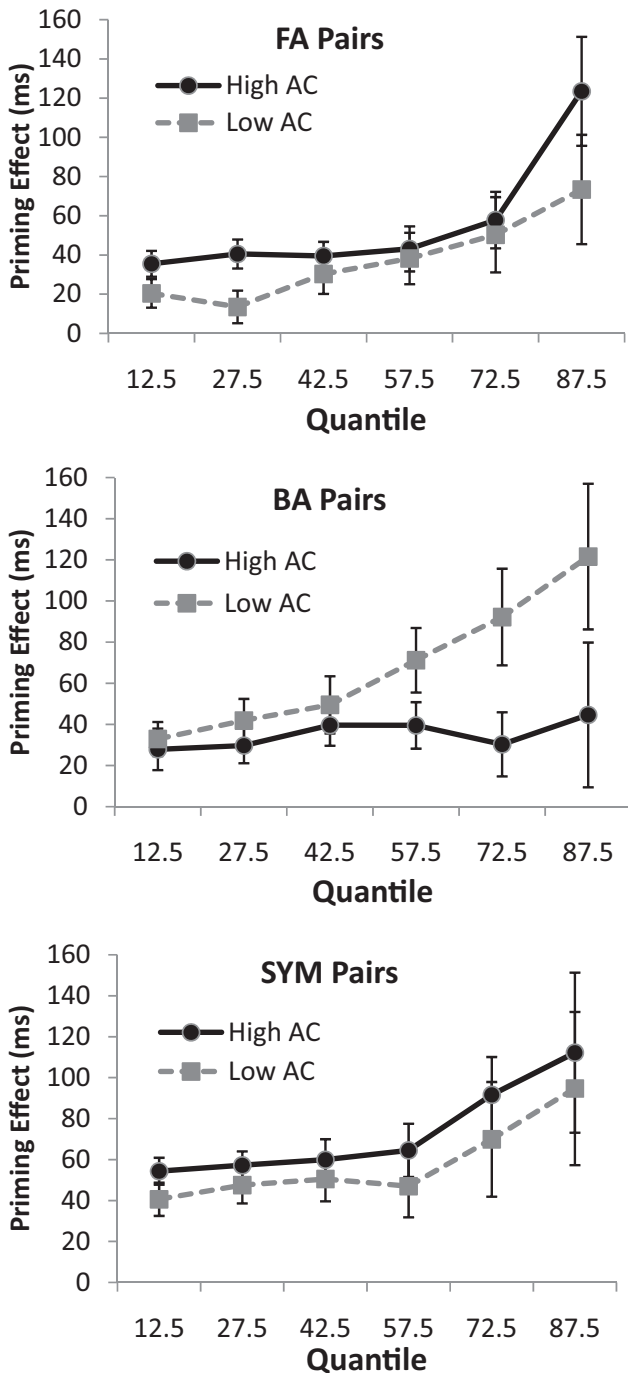


Figure 2. Distributional FA, BA, and SYM priming effects for high-versus low-AC quartiles. Error bars reflect the standard error of the mean for priming effects (i.e., unrelated reaction time [RT] minus related RT) in each condition. FA = forward associates; AC = attentional control; BA = backward associates; SYM = symmetric associates.

cant three-way interaction between AC group, type of association, and RT bin, $F(1, 107) = 2.77$, $MSE = 11,606$, $\eta_p^2 = .03$, $p = .099$. For FA priming, high-AC individuals showed a significantly greater 21 ± 19 -ms FA priming effect than low-AC individuals in

the early bin, $t(107) = 2.22$, $p < .03$, and a nonsignificant 29 ± 54 ms greater FA priming effect in the late bin, $t(107) = 1.04$, $p = .30$. For BA priming, planned comparisons revealed that low-AC individuals showed a marginally significant 69 ± 69 ms greater BA priming effect than high-AC individuals in the late bin, $t(107) = 1.97$, $p = .05$, but a nonsignificant 9 ± 24 -ms advantage in the early bin, $t(107) = 0.71$, $p = .48$. Because the one degree of freedom three-way interaction and the advantage for late BA priming among low-AC individuals were both marginally significant effects ($p = .099$ and $.05$, respectively), they should be treated with caution. However, both effects were predicted a priori and would be significant by a one-tailed test. The opposite patterns of AC effects on FA and BA priming, in which the high-AC advantage in FA priming occurred early in the RT distribution, whereas a possible low-AC advantage in BA priming occurred only late, provides further evidence (albeit of marginal statistical significance) that priming for high- and low-AC individuals is produced by dissociable mechanisms. This pattern provides support for the hypothesis that high-AC individuals are more likely to use a prospective (i.e., proactive) strategy such as expectancy generation, whereas low-AC individuals may be more likely to use a retrospective (i.e., reactive) process such as semantic matching.

Discussion

The most critical finding from the present study was that FA and BA priming were differentially moderated by AC. Overall, as predicted, FA priming increased with increasing AC, and a high-AC quartile advantage in FA priming emerged early in the RT distribution. These results are consistent with Hutchison's (2007) finding that when RP was cued by the prime's font color, RP effects in pronunciation were linearly related to AC. The most plausible explanation for these combined findings is that those high in AC are more likely to engage a proactive expectancy strategy of using primes to generate possible related targets (Becker, 1980). As discussed by Balota et al. (2008), prelexical processes such as expectancy should produce a general shift in priming across the entire RT distribution.

The AC difference in FA priming mimics an observation by Hutchison et al. (2008) that young adults produce more priming than older adults, once lexical decision RTs are transformed to z scores to control for baseline differences in RT. This age difference is likely due to young adults' greater use of expectancy generation because the Hutchison et al. (2008) items had unusually high-FA strengths, with 97% of his 300 items having FA strengths of .50 or greater, which would have supported enhanced expectancy-based priming. In contrast, the BA strengths were much lower (only 15% at or above .50). To examine the role of FA strength in Hutchison et al.'s age effect, we first reexamined their data set for an effect of age on priming at the item level. As with their reported subject-level analysis, we found a significant age effect in z -score priming at the item level, $F(1, 299) = 4.61$, $MSE = .10$, $\eta_p^2 = .02$, with $.06 \pm .05$ standard deviations greater priming for young adults than older adults (z -score priming effects of $.42 SD$ and $.36 SD$, respectively). However, when FA strength of items is entered as a covariate, this age effect is no longer significant, $F(1, 298) = 1.28$, $MSE = .10$, $\eta_p^2 = .00$. Further, when we split the 300 items into highest ($M = .79$), middle ($M = .65$), and lowest ($M = .53$) tertiles of FA strength, the age effect in

semantic priming diminished along with decreasing FA strengths from $.12 \pm .09$, to $.06 \pm .09$, to $-.01 \pm .09$, respectively. Thus, consistent with the present finding of greater FA priming for high-AC individuals, the priming advantage for young adults in Hutchison et al. (2008) was primarily due to FA priming from easily predicted strong FAs.

There was also a hint in the present study that BA priming may be greater for low-AC individuals than high-AC individuals. Specifically, low-AC individuals had marginally higher ($p = .05$) BA priming effects than high-AC individuals in the predicted later portions of the RT distribution. This finding suggests that low-AC individuals may be more reliant on a reactive control process such as retrospective semantic matching. As argued by Balota et al. (2008), the contribution of such a retrospective process should become more pronounced during later stages of the RT distribution because semantic matching cannot be initiated until after the target is presented.

Overall, the present data are consistent with predictions from Braver et al.'s (2007) dual-mechanisms-of-control model. According to Braver et al., individuals high in working memory capacity (WMC) often rely on effortful, yet effective, proactive control strategies when environmental cues are predictive of targets (i.e., when the RP is sufficiently high). In contrast, high WMC is not necessary for reactive control strategies that involve retrieval (rather than maintenance) of contextual information. Although Braver et al.'s theory is noncommittal on whether proactive and reactive strategies should interact, there is some current evidence that semantic matching may compensate for deficient proactive expectancy.

The present data add to recent evidence from very disparate domains in psychology for WMC differences in utilization of proactive and reactive processes. For instance, in the Stroop task, Kane and Engle (2003; see also Hutchison, 2011) found that in lists consisting of mostly congruent items, high-WMC individuals were more likely than low-WMC individuals to maintain the name-the-ink-color/ignore-the-word task goal across trials (i.e., proactive control), thereby reducing their Stroop interference relative to low-WMC individuals. However, for lists consisting of mostly incongruent items, which served as frequent reminders of the needed task goal, high- and low-WMC individuals showed equivalent Stroop effects. Moreover, low-AC individuals are more sensitive to conditional response contingencies between to-be-ignored distractor words and the correct color responses in Stroop tasks (Hutchison, 2011). This latter, reactive, effect supports the present claim that low-AC individuals may be more influenced by the conditional response probabilities involved in word/nonword responding. Similarly, within the prospective memory literature, McDaniel and Einstein (2000; see also Marsh & Hicks, 1998) argued that high-WMC individuals are more likely to maintain prospective memory targets in working memory during an ongoing task, whereas low-WMC individuals are instead more likely to rely on spontaneous retrieval of prospective memory cues upon target presentation. Finally, the notion that target onset automatically cues prime retrieval is consistent with automatic retrieval accounts of practice effects (Logan, 1988) and distributed practice benefits in memory (Benjamin & Tullis, 2010).

Perhaps the most similar analogy for the dual prospective and retrospective mechanisms proposed here are the prospective inhibitory (Tipper, 1985) and retrospective retrieval processes (Neill,

1997) suggested as explanations for negative priming (i.e., the finding that probe target processing is impaired if a similar item was ignored on a recent prime trial). Specifically, inhibition of distractors during a prime trial is supposedly sensitive to individual (and group) differences in AC (May, Kane, & Hasher, 1995), whereas episodic retrieval of the ignored prime is supposedly an automatic consequence of probe-target processing (Neill et al., 1992). By manipulating the target repetition proportion (TRP) in their experiment, Kane, May, Hasher, Rahhal, and Stoltzfus (1997) confirmed the hypothesis that older adults have deficient inhibitory processing and therefore would only show negative priming under conditions that favor episodic retrieval (e.g., a high TRP). More recently, Tse, Hutchison, and Li (2011) conducted an RT distributional analysis of negative priming under conditions that either encourage episodic memory retrieval (e.g., high TRP and/or same context from prime to probe trials) or discourage episodic memory retrieval (e.g., different context and low TRP). When episodic retrieval was discouraged, there was a small negative priming effect that produced an overall shift in the RT distribution, indicative of prospective inhibition. However, when episodic retrieval was encouraged, they found increased negative priming that primarily affected the later RT bins, indicative of response-related interference due to memory retrieval. These results converge with our present data in suggesting both a resource-dependent prospective mechanism that produces an early influence on target processing and an automatic response-relevant retrieval mechanism (Hommel, 2004) that primarily affects the tail end of the RT distribution.

When considered in conjunction with Hutchison's (2007) results, the present data imply that expectancy generation is indeed an intentional, effortful process (because its contribution to priming increases as AC increases), whereas semantic matching is not. (As discussed in the introduction, the fact that semantic matching involves the calculation of complex conditional probabilities does not mean participants are consciously aware of such probabilities and their influence on responding; e.g., Schmidt, Crump, Cheesman, & Besner, 2007.) However, the short-SOA BA and FA priming effects that we observed pose problems for the original version of the three-process model. Specifically, this model claims that short-SOA priming should be driven solely by automatic spreading activation, whereas long-SOA priming should be more strongly governed by strategic factors. As a result, (a) BA priming should be absent at the short SOA and (b) AC differences should emerge only at the long SOA. Our data conflict with both of these predictions. Short-SOA BA priming (56 ms) was at least as large as long-SOA priming (42 ms), and the correlation between AC and FA priming was actually numerically greater, not smaller, at the short SOA, $r(214) = .18$, $p = .01$, relative to the long SOA, $r(214) = .11$, $p = .13$. However, both of these findings are consistent with other findings that have been obtained after the three-process model's original formulation.

Our finding that BA priming occurs at a short SOA replicates the prior results of Kahan et al. (1999) and Thompson-Schill, Kurtz, and Gabrieli (1998) (see Hutchison, 2003, for a review). These results contradict Neely's (1991) claim that BA priming is produced by semantic matching, which only operates at longer SOAs. The SOA claim was based on the finding that the nonword facilitation effect (faster nonword target RTs following unrelated primes relative to neutral primes), which is the signature for

semantic matching, increases as SOA increases (Antos, 1979; de Groot, Thomassen, & Hudson, 1986; Favreau & Segalowitz, 1983; Neely, 1976, 1977). That BA priming occurs at a short SOA suggests that either these BA priming effects are produced by a mechanism other than semantic matching or that semantic matching does not require a long SOA. These possibilities need to be addressed by future experiments that are specifically designed to address them, which the present experiment was not.

Our finding that short-SOA FA priming is affected by AC is inconsistent with the long-standing claim that expectancy-based priming requires at least 400 ms to implement (Neely, 1977). However, over the past decade, there has been converging evidence (Hutchison, 2007; Hutchison, Neely, & Johnson, 2001) that RP effects (often considered a marker for expectancy) occur at SOAs as short as 267 ms but not 167 ms, at least for the type of strong associates used in the present study. On the basis of their results, Hutchison et al. (2001) and Hutchison (2007) argued that the speed with which expectancies can be generated likely varies as a function of participant, prime–target relation, and practice. Consistent with results from the present study, RP effects in the Hutchison (2007) paradigm linearly increased with AC when primes were presented in the high-RP font color. Moreover, the color-cued RP procedure precludes an explanation based on AC differences in automatic spreading activation, because this would have produced equal priming effects regardless of the RP-specifying prime color. Finally, consistent with our present finding that increased FA priming for high-AC individuals did not interact with SOA, Hutchison (2007) found that the increased RP effect for high-AC individuals did not interact with SOA (267 ms vs. 1,240 ms). Thus, Hutchison's (2007) results and our data provide converging demonstrations that, compared with low-AC individuals, high-AC individuals are more capable of generating strong-associate targets quickly and maintaining them across a delay.

A Caution Regarding Correlations

Because AC is a measured, rather than manipulated, variable, AC differences in priming can be due to other potential differences between subjects (e.g., vocabulary, reading fluency, motivation, perceptual ability, etc.). Unfortunately, we did not collect additional measurements from our participants that would allow us to rule out these potential confounding variables, which have previously been shown to correlate with semantic priming, as having produced our effects. For instance, Stanovich (1980) developed an interactive-compensatory model based on individual differences in reading fluency, suggesting that those lower in reading fluency are more reliant on strategically using the preceding context to decode target words (i.e., expectancy). Stanovich et al. (1981) demonstrated that context effects on target word RT decreased when participants were given isolated practice on the target words. Although originally framed in terms of expectancy versus spreading activation, the interactive-compensatory model can be supplemented with a semantic matching component such that poor readers may be more dependent on semantic matching than good readers. Similarly, Yap, Tse, and Balota (2009) found that only participants with low vocabulary scores showed an increase in priming for low-frequency words relative to high-frequency words, and this effect emerged solely for longer RTs. If we assume a positive correlation between AC and reading fluency/vocabulary,

this could explain our trend toward greater BA priming for low-AC than high-AC individuals for longer RTs. Specifically, low reading fluency/vocabulary individuals may be more likely to use semantic matching on low-frequency targets, producing greater BA priming through stretching the tail of the RT distribution associated with long RTs.

Although the interactive-compensatory account posits that it is the poor readers who are more likely to strategically use context to aid in word recognition, a positive correlation between AC and individual differences in lexical integrity/reading fluency could nonetheless explain an AC difference in FA priming, at least at a short SOA. If it is assumed that prospective mechanisms such as spreading activation and expectancy generation are dependent on the ability to quickly recognize primes, high reading fluency/vocabulary individuals should be better able to quickly recognize prime words, allowing for a greater contextual influence from these primes. Supporting this claim, Hutchison et al. (2008) found that prime frequency was indeed positively correlated with priming effects at a 200-ms SOA, but not at a 1,200-ms SOA. This explanation incorrectly predicts that AC differences in FA priming (if due to differences in reading fluency/vocabulary) should only occur at the short SOA; however, AC differences in priming were equivalent for our short and long SOAs. This explanation also incorrectly predicts that BA priming for low-AC individuals should only occur at the long SOA because primes must be sufficiently processed to allow for semantic matching; however, BA priming was equivalent for the short and long SOAs.

Finally, Plaut and Booth (2000) argued that a single-mechanism distributed network model can accommodate complex priming patterns by postulating a nonlinear sigmoid mapping between input and output units (see Plaut & Booth's Figure 1) and differential connection strengths between letter strings and their corresponding semantic units based on factors such as participants' perceptual ability and target word frequency (see Plaut & Booth, 2000, for a more detailed description of their model). The Plaut and Booth model could, in principle, explain greater priming for either low- or high-AC participants if we assume that AC correlates with perceptual ability. However, because Plaut and Booth assume that FA and BA priming effects are produced by the same mechanism and because they have no mechanism for AC, it cannot, without considerable embellishment, explain the disordinal effects that FA and BA priming had for our high- and low-AC participants. In addition, the Plaut and Booth model cannot explain why Hutchison's (2007) color-cued RP effects could occur at all, much less only for high-AC individuals. Specifically, Plaut and Booth (p. 814) explained RP effects on priming by assuming that participants use a more lenient criterion for responding in high-RP blocks, because the separation between word and nonword activation levels is greater on average when there is a preponderance of high-activation-related targets. However, in Hutchison (2007), the high- and low-RP color cues were randomly presented in a list in which the overall proportion of related word targets was .5.

In summary, because of the correlational nature of the present study, there are multiple potential alternative accounts for our findings. However, none of these accounts offers a completely satisfactory explanation for our complete pattern of data, and none can explain Hutchison's (2007) allied pattern of RP effects. Therefore, we believe that differences in priming between high- and low-AC individuals reflect their differential use of proactive ver-

sus reactive strategies. For future research, we recommend that researchers address these alternative accounts based on confounding variables by testing FA and BA priming across SOAs while directly manipulating working memory load. This would provide more direct evidence on the role of AC on FA and BA priming.

A final interpretive issue is whether strategy differences between high- and low-AC individuals are due to ability or preference. In Braver et al.'s (2007) dual-mechanism-of-control model, low-WMC individuals are described as lacking sufficient resources to engage the more metabolically taxing proactive control strategies. However, in the present study, the presumed AC differences in proactive versus reactive strategy utilization could arise out of either ability or preference. This is so because either strategy would be effective for two thirds of the present related prime-target pairs. That is, expectancy would be useful for the FA- and SYM-related pairs but not the BA-related pairs, whereas semantic matching would be useful for the BA- and SYM-related pairs but not the FA-related pairs. Thus, one could argue that low-AC individuals are performing more efficiently than high-AC participants by choosing the less effortful, but equally effective reactive semantic-matching strategy instead of the more effortful proactive expectancy strategy used by high-AC individuals.⁵ In this case, high-AC participants' use of expectancy, even when unnecessary, might reflect their stable preference for preparatory control that they have learned dominates performance in most tasks. Although we cannot distinguish ability from preference in the present study, the Hutchison (2007) results suggest that high- versus low-AC differences are rooted in ability differences. Specifically, he used a speeded pronunciation task, which, as noted earlier, should benefit little if at all from semantic matching (see Neely, 1991, for a review) at least for clear targets with a long SOA.⁶ Moreover, in Hutchison's paradigm, participants were informed about the different prime color-RP contingencies and encouraged to engage expectancies for related targets following a high-RP prime. However, despite this encouragement and the small benefit that would be conferred by an alternative reactive strategy such as semantic matching, low-AC individuals still showed no evidence for expectancy use. This suggests that the AC difference in strategy reflected, at least partly, underlying cognitive resources, rather than simple preference.

Conclusion

In the present study, we found evidence for qualitative differences in semantic priming between high- and low-AC individuals. High-AC individuals showed greater FA priming than low-AC individuals, and this was evident even early in the RT distribution, indicative of a prospective priming mechanism such as expectancy generation. In contrast, low-AC individuals showed greater BA priming than high-AC individuals in the later portions of the RT distribution, consistent with a semantic-matching account. However, this AC difference for BA priming for the longest RTs should be treated with caution, as it was only marginally statistically significant ($p = .05$). Taken together, then, the extant priming data are therefore generally supportive of Braver et al.'s (2007) dual-mechanism model of cognitive control in which those high in AC engage processing resources to use proactive control as long as environmental cues are helpful, whereas low-AC individuals more often rely on reactive retrieval processes triggered by the onset of

target stimuli. These priming results are consistent with recent Stroop performance evidence from high- and low-WMC individuals, showing that high-WMC individuals exert more proactive goal maintenance control across trials, whereas low-WMC individuals instead rely more on reactive stimulus-driven mechanisms of control that operate within trials (Hutchison, 2011; Kane & Engle, 2003).

⁵ We thank David Balota for bringing this possibility to our attention.

⁶ As have others, Thomas et al. (2012) failed to find a significant overall BA priming effect in pronunciation at a long SOA, though the effect was significant for the ninth and 10th deciles in their distributional analysis.

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