

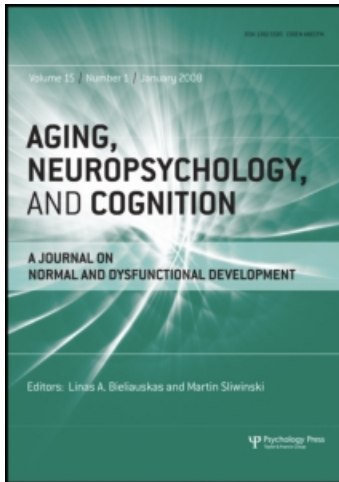
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# Adult Age Differences in Attention to Semantic Context

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## ABSTRACT

In three experiments age differences in attention to semantic context were examined. The performance of younger adults (ages 18–29 years) and older adults (ages 60–79 years) on a semantic priming task indicated that both age groups could use information regarding the probability that a prime and target would be related to flexibly anticipate the target category given the prime word (Experiment 1). The timing by which target expectancies were reflected in reaction time performance was delayed for older adults as compared to younger adults, but only when the target was expected to be semantically unrelated to the prime word (Experiment 2). When the target and prime were expected to be semantically related, the time course of priming effects was similar for younger and older adults (Experiment 3). Together the findings indicate that older adults are able to use semantic context and the probability of stimulus relatedness to anticipate target information. Although aging may be associated with a delay in the timing by which controlled expectancies are expressed, these findings argue against an age-related decline in the ability to represent contextual information.

**Keywords:** Aging; Attention; Semantic priming; Context processing; Controlled expectancies.

## INTRODUCTION

Cognitive processing is enhanced when targeted information is embedded within a meaningful context. Theories of cognitive aging have proposed that the cognitive performance of older adults benefits at least as much as that of younger adults from a semantically supportive context. For example, the

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environmental support hypothesis of Craik and colleagues (Craik, 1994; Craik & McDowd, 1987; Craik, Byrd, & Swanson, 1987) contends that memory retrieval is more likely to be successful if the retrieval context is similar to the context present during encoding. The theory further proposes that age differences in retrieval that are associated with reduced processing resources are minimized when the encoding context is re-instantiated at retrieval. Similarly, according to the integration hypothesis of Park, Smith, and colleagues (Park, Smith, Morell, Puglisi, & Dudley, 1990; Smith, Park, Earles, Shaw, & Whiting, 1998), integrating to-be-remembered information with semantically supportive contextual cues should facilitate memory more than neutral cues, and this effect should be particularly pronounced for older adults.

Studies that have tested these theories have largely found support for older adults' ability to use context to enhance memory. For example, in a paired associate task, Park et al. (1990) varied the pre-existing relationship between pictorial cues and target pictures and found large age differences in picture recall (with poorer recall for older adults) when contextual cues were unrelated to the target items but much smaller age differences when contextual cues were related to the targets. In many cases, older adults have benefited as much as younger adults when a meaningful context is used relative to a neutral context (Cherry & Park, 1993; Earles, Smith, & Park, 1994; Naveh-Benjamin, Craik, & Ben-Shaul, 2002; Smith et al., 1998).

### **Aging and Attention to Context**

In contrast to the environmental support theory, Braver and Barch (2002) proposed that older adults are less able to process contextual information, and that this age-related limitation accounts for impairments in a variety of cognitive processes, including attention, episodic memory, and executive function. Support for Braver and Barch's theory came from studies using the AX-Continuous Performance Test (AX-CPT; Braver et al., 2001; Braver, Saptune, Rush, Racine, & Barch, 2005; Paxton, Barch, Storandt, & Braver, 2006; Rush, Barch, & Braver, 2006). From a stream of letters participants are instructed to make a target response to a frequent two-letter sequence (AX). Because the AX pairing constitutes 70% of the trials, the context (the letter A) becomes predictive of the target's appearance (the letter X) and directs attention to a particular response. The use of context to prepare a response was evident on non-target trials in terms of higher error rates when the frequent first letter (A) was paired with a non-target second letter (e.g., Y). In other words, the response (incorrectly identifying the second letter as the target) was based on the context more so than on the stimulus. Poor use of context was evident in terms of higher error rates when the frequent second letter (X) was paired with a non-target first letter (e.g., B), indicating that participants made a target response based on the second letter without

first considering the prior contextual information. Younger adults' performance was consistent with intact context processing (more AY errors), whereas older adults' performance reflected compromised context processing (more BX errors). Older adults represented contextual information but not in a proactive manner to generate expectancies for the upcoming target letter (Braver et al., 2005). However, with strategy training or extended practice, older adults' performance could become more like that of younger adults (more errors on AY trials, fewer errors and faster RTs on BX trials; Paxton et al., 2006, Experiment 2).

### **Attention to Context in the Semantic Priming Paradigm**

The AX-CPT task assesses the ability to attend to context with the purpose of anticipating upcoming information and preparing an appropriate response. Although there is no pre-existing association between the context and the target information, consistent pairings across trials leads observers to expect the target given the context. This conceptualization of context contrasts with that used in the memory studies described above, in which context was presented with the purpose of facilitating the recall of information that was previously presented in that context. An additional difference between the two literatures is that in the memory studies, a semantically meaningful relationship between the two items (the context and the to-be-remembered information) had been found to minimize age differences when the encoding context was reinstated at retrieval as compared to a semantically neutral pairing. The AX-CPT task assesses attentional control within novel contexts (pairings of two unrelated letters, A and X). A task that has assessed attention to a semantically meaningful context is the semantic priming paradigm.

In the semantic priming task, participants are shown a prime and target pair. The semantic priming effect reflects faster responses to target words preceded by semantically related primes (DOG–cat) as compared to unrelated primes (CHAIR–cat) or neutral primes (xxxx–cat). Neely (1977) proposed that two processes contribute to semantic priming performance. In addition to attention-based expectancies, there is an automatic activation process. In automatic priming, activation of one semantic representation (i.e., DOG) spreads quickly, automatically, and without awareness to associated words (i.e., cat) or categories (i.e., types of dogs) because of over-learned associations within semantic memory. Automatic activation is reflected in performance at very short cue–target intervals and cannot be interrupted. With attention-based expectancies, on the other hand, participants form a conscious strategy to use the prime identity to anticipate a related or unrelated target, depending on characteristics of the task. Based on this expectancy, participants voluntarily direct attention toward semantic relationships or categories. This conscious strategy (process the prime, determine the most

likely target, and prepare the appropriate response) takes time to implement and thus is not effective at very short prime–target intervals but impacts performance at longer prime–target intervals.

The particular configuration of prime–target relatedness proportion and prime–target timing influences whether automatic activation or controlled expectancies will more dominantly contribute to priming performance (Neely, 1977). For instance, if .80 of trials are related (.20 are unrelated), participants will learn to expect to see related pairs, and both controlled expectancies (prepare for a response associated with a related target) and automatic activation (spreading activation to related words) will lead to faster responses in the related condition as compared to the unrelated condition, with the former process guiding performance at short prime–target intervals and the latter process impacting performance at longer prime–target intervals. However, if .20 of the trials are related (.80 unrelated) participants will learn to expect to see unrelated word pairs, and controlled expectancies will lead to faster responses in the unrelated condition as compared to the related condition, whereas automatic activation will still lead to faster responses in the related as compared to the unrelated condition (through spreading activation of related items). Under such conditions, task timing characteristics play an important role in determining the observed pattern of priming performance. At short intervals between the onsets of the prime and the target (e.g., 100 ms), the relatedness proportion will have little effect on performance because automatic activation processes predominate, resulting in quicker responses to related than unrelated targets, no matter how often the items are related. However, at longer prime–target onset intervals, for example, a stimulus onset asynchrony (SOA) of 600 ms, participants will have time to utilize the relatedness proportion information and act upon controlled expectancies for upcoming information. With reduced influence of automatic activation at later prime–target intervals, responses will be quicker to unrelated targets than related targets.

To examine age patterns in automatic activation and controlled expectancies, Burke, White, and Diaz (1987) tested younger and older adults on a semantic priming paradigm that used two prime–target SOAs (410 and 1550 ms), two relatedness conditions (related and unrelated), and two relatedness proportions (.80 related or .20 related). The prime words named two categories (TREE and VEGETABLE), and participants were instructed to expect target words from the same category with one prime (e.g., TREE–elm) and to expect target words from a different but specified category (weather) with the other prime (e.g., VEGETABLE–fog). Results indicated similar patterns of performance for younger and older adults. At the short SOA (but not at the long SOA), responses were faster to the related condition as compared to the unrelated condition, regardless of the relatedness proportion, consistent with automatic activation. At both the short and long SOAs, RTs were faster

to the expected target (a related target for one prime and an unrelated target for the other prime) as compared to the unexpected target, regardless of relatedness, and this expectancy effect was greater at the long SOA. The authors concluded that older adults formed attention-dependent expectancies similarly to younger adults. Balota, Black, and Cheney (1992) used similar task manipulations and found response patterns consistent with automatic activation at the short SOA (250 ms) and controlled expectancies at the longer SOAs (1000 and 1750 ms). However, older adults showed a decrease in the controlled expectancy effect from 1000 to 1750 ms (Experiment 1). Maintaining the prime on the screen during the prime–target interval to decrease cognitive load eliminated the age-related decrease in expectancy effects (Experiment 2). The researchers concluded that older adults can form expectancies similarly to younger adults, but that older adults may be less able to maintain expectancies at longer prime–target intervals unless additional contextual support is provided.

### **The Present Study**

Braver and Barch's (2002) context processing theory with later modifications (Braver et al., 2005; Paxton et al., 2006) proposed that older adults have difficulty using context in a predictive manner unless given sufficient training or practice. This theory and the findings that support it were based on the AX-CPT task. However, findings from the semantic priming task have indicated that older adults are able to proactively anticipate target information based on semantic context (Balota et al., 1992; Burke et al., 1987). In both the AX-CPT task and the semantic priming task, there are regular pairings of stimuli that encourage participants to anticipate the target stimulus when presented with the cue or prime stimulus. Three prominent differences between the two paradigms are the use of an established context, the instructions provided, and the number of trials typically completed. In the semantic priming task, participants can call on well-learned semantic contexts, which should provide additional environmental support for older adults, whereas in the AX-CPT task participants must establish a novel association between letters (A and X). In addition, the instructions provided in semantic priming studies typically emphasize the relatedness proportions used in the study (e.g., most of the time the prime and target will be related or most of the time the prime and target will be unrelated) to encourage the use of controlled expectancies, whereas the high proportion of AX trials in the AX-CPT task is not typically described as part of the participant instructions. Finally, studies using the semantic priming paradigm typically include 300–500 trials, whereas it is not unusual for studies using the AX-CPT task to use a single block of 100 trials. Both the explicit instructions and greater number of trials in the semantic priming task likely encourage participants to notice the relatedness proportions in the experiment, which in turn encourages participants

to use an anticipatory response preparation strategy. All these factors are likely candidates for explaining why age-related deficits in anticipatory responding are evident on the AX-CPT task but not on the semantic priming task.

The purpose of the present study was to test the limits of older adults' ability to use contextual cues to guide attention on the semantic priming task. In the first of three experiments, we examined older adults' ability to not only form controlled expectancies quickly (within 100 trials) but also to flexibly adjust those expectancies as the probability that primes and targets would be related changed. In separate blocks of trials, the probability that the target word belonged to the semantic category named by the prime word was manipulated so that in one block, the target word was most likely to come from the semantic category of the prime word (.80 probability that the prime and target were related), whereas in another block the target word was most likely to come from the other semantic category (.20 probability that the prime and target were related). In a third block, the target word was equally likely to come from the category named by the prime word as from the other category (.50 probability that the prime and target were related). We were interested in whether the performance of both older adults and younger adults would reflect a switch from expecting primes and target to be related on most trials (in the .80 relatedness condition) to expecting primes and targets to be unrelated on most trials (in the .20 relatedness condition). We also assessed the time point at which controlled expectancies would outweigh automatic activation effects in determining priming performance (Experiments 2 and 3), to determine whether age differences existed in the time course by which expectancies were revealed in performance.

Because the current priming paradigm built on established semantic relationships, older adults were predicted to form expectancies for the category membership of the target. However, because in one block of trials the prime and target were most likely to be unrelated, and because participants were being called upon to adjust expectancies from one block to the next, there was the possibility that older adults would have more difficulty than younger adults (a) switching attention from the category named by the prime to the expected target category in the .20 relatedness condition and (b) switching expectancies between blocks. As suggested by the Braver and Barch findings (Braver et al., 2001; Rush et al., 2006), older adults may have had difficulty anticipating target information within novel contexts. In addition, there is evidence from other paradigms that older adults have difficulty efficiently switching attention between mental sets or response sets (Hahn, Andersen, & Kramer, 2004; Mayr & Liebscher, 2001). Although previous age-related findings on semantic priming tasks (Balota et al., 1992; Burke et al., 1987) have indicated that given clear instructions about prime–target relatedness, older adults were able to form controlled expectancies based on semantic

information, we predicted that with so few trials and with varying semantic relatedness, that younger adults would demonstrate target category expectancies within 100 trials, whereas older adults' expectancy effects would be smaller or less consistent (Experiment 1).

To our knowledge, no study has yet examined age differences in the time needed for expectancies to be reflected in behavior, so no clear predictions were made regarding the patterns of expectancy effects at different prime–target intervals. However, attentional orienting studies have indicated that older adults often respond to spatial cue information on a different time course than younger adults, with facilitation effects sustained at longer cue–target intervals for older adults than for younger adults, and inhibition effects slower to be reflected in older adults' performance or slower to resolve (Castel, Chasteen, Scialfa, & Pratt, 2003; Langley, Fuentes, Hochhalter, Brandt, & Overmier, 2001; Langley, Fuentes, Vivas, & Saville, 2007). Thus, we hypothesized that the performance of older adults would reflect longer lasting automatic priming effects at early prime–target intervals and slower developing expectancy effects at later intervals (Experiments 2 and 3).

## EXPERIMENT 1

In Experiment 1 we addressed the question of whether older adults could form and flexibly adjust attentional expectancies to match the prime–target relatedness proportions of the task. As a within-subject manipulation, participants were exposed to three relatedness proportions: .80, .50, and .20. When presented with the word ANIMAL or TREE (prime) followed by an example of an animal or a tree (target), the participants' task was to categorize the second word as quickly as possible. The instructions at the beginning of a block described the association between the prime and the target. In the .80 condition, participants were informed that most of the time the first word would be followed by a word from the same category. In the .50 condition, participants were informed that the second word was just as likely to come from the category named by the first word as from the other category. In the .20 condition, participants were informed that most of the time the first word would be followed by a word from the other category. In all cases, the participants were told that paying attention to the first word would help them categorize the second word more quickly. We used a prime–target interval that was sufficiently long (SOA of 800 ms) for controlled expectancies to have an impact on performance (Burke et al., 1987; Neely, 1977).

If participants used the information about the relatedness proportion to prepare a response to the target, then we expected their responses to be (a) faster in the related condition than in the unrelated condition in the .80 condition, (b) of similar latency in the related and unrelated conditions in the .50



condition, and (c) faster in the unrelated condition than in the related condition in the .20 condition. Based on past evidence that older adults can form controlled expectancies on a semantic priming task (Balota et al., 1992; Burke et al., 1987), we predicted that both younger adults and older adults would display this pattern of performance. However, the present task was a strong test of expectancies, because not only did older adults need to create expectancies based on the instructions and the relatedness proportion information, but they also needed to flexibly adjust those expectancies from one block to the next, given only 100 trials per block. Because we believed that older adults would be less able to make these adjustments efficiently, we predicted that the magnitude of the expectancy effect would be reduced in older adults as compared to younger adults. This age difference may have been accentuated in the .20 condition, in which pre-existing associations did not support the semantic context.

## Method

### *Participants*

Thirty-six younger adults (22 women, 14 men) in the age range of 18–28 years and 36 older adults (21 women, 15 men) in the age range of 61–79 years were tested and included in the data analysis. Demographic and psychometric data for the two groups are reported in Table 1. Younger adults were students at North Dakota State University who received course extra credit for participating; older adults were from the Fargo-Moorhead community and received \$10/h for their time. According to self-report on a health screening questionnaire (Christensen, Moye, Armson, & Kern, 1992), all participants were free of serious medical conditions that could impair cognitive functioning (e.g., heart disease, stroke, neurological diseases such as Parkinson's disease or Alzheimer's disease, or drug or alcohol abuse). All participants had a minimum of a high school education and spoke English as their first language. Corrected near visual acuity was 20/40 or better as assessed with a Snellen near acuity eye chart (Precision Vision, La Salle, IL). All participants scored 9 points or lower on the Geriatric Depression Scale (GDS; Yesavage et al., 1982), indicating minimal depressive symptomatology, and 26 points or higher on the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975), demonstrating no observable signs of significant cognitive impairment. As indicated in Table 1, younger adults had significantly better visual acuity than older adults. In addition, older adults scored significantly better than younger adults on the vocabulary subscale of the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999), which was used as an estimate of crystallized intelligence. It is not uncommon to find higher vocabulary scores among older adults (Verhaeghen, 2003), and taken together with significantly more years of

TABLE 1. Participant characteristics for Experiments 1, 2, and 3

	Experiment 1				Experiment 2				Experiment 3			
	Mean		SD		Mean		SD		Mean		SD	
	YA	OA	YA	OA	YA	OA	YA	OA	YA	OA	YA	OA
Age (years)	20.8*	67.9	2.1	4.6	20.2*	68.4	3.0	5.9	19.8*	68.5	1.5	4.5
Education (years)	14.3*	15.3	1.4	2.7	13.8*	15.6	1.3	2.6	13.9*	16.6	1.2	3.7
WASI vocabulary (80 max)	59.6*	69.0	6.4	5.6	57.8*	67.0	6.2	7.7	57.6*	67.2	6.1	7.1
Snellen acuity (20/___)	16.2*	23.5	3.5	6.1	16.0*	23.0	3.7	6.6	15.9*	24.2	3.9	7.0
MMSE (30 max)	29.5	29.5	0.7	0.8	29.6	29.3	0.8	0.8	29.4	29.3	0.9	0.9
GDS (30 max)	1.3	1.3	1.9	1.9	1.5	1.5	1.6	1.7	1.9	1.4	2.0	1.9

*Note:* SD, standard deviation; YA, younger adult group; OA, older adult group; WASI, Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999). Maximum score on the vocabulary subscale is 80 points, with a higher score indicating better performance. Snellen acuity, denominator of the Snellen fraction for corrected near vision. A smaller number indicates better vision. MMSE, Mini Mental State Examination (Folstein, Folstein, & McHugh, 1975). Maximum score is 30 points, with a higher score indicating better performance. GDS, Geriatric Depression Scale (Yesavage et al., 1982). Maximum score is 30, with a higher score indicating endorsement of more depressive symptoms.

\* Indicates that mean scores differed between age groups according to independent *t* test,  $p < .05$ .

education on the part of older adults, it appears that the present older sample was a high functioning group.

### Materials and Stimuli

Stimuli were displayed on a 17-inch color monitor (refresh rate of 85 Hz) controlled by a PC computer with a Pentium 4 processor. Responses were made on a five-button PST Serial Response Box, model number 200A (Psychology Software Tools, Pittsburgh, PA), and a chin rest maintained the participant's viewing distance at 40 cm.

The experimental task was created using E-Prime, Version 1.0 (Psychology Software Tools, Pittsburgh, PA). Stimuli were presented against a black background in two vertically arranged white unfilled boxes with visual angles of 12.6° in width by 4.7° in height. The centers of the two boxes were separated by 7.4°. The prime stimuli were the words TREE and ANIMAL presented in uppercase letters, 1.3° in height and 3.9° (TREE) or 4.9° (ANIMAL) in width. Target words were examples of trees (*oak, elm, maple, and pine*) and animals (*horse, dog, lion, and cat*) that were 1.2° in height and on average 3.1° (range=2.3–3.9°) in width and presented in lowercase letters. Both primes and targets were presented in white Arial font.

There were two levels of prime–target relation (related and unrelated) and three levels of relatedness proportion (.80, .50, and .20). In the related

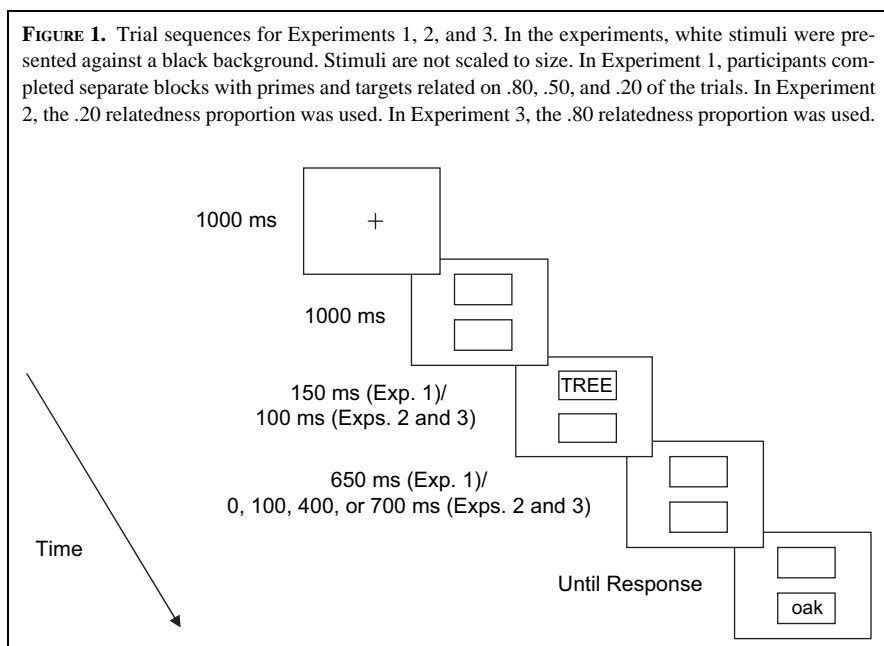
condition the target (e.g., oak) matched the category of the prime (e.g., TREE). In the unrelated condition the target (e.g., oak) did not belong to the prime category (e.g., ANIMAL), but instead came from the other category. To encourage the formation and use of attention-dependent expectancies, the relatedness proportion conditions manipulated the proportion of trials in which the target was semantically related to the prime category. In each relatedness proportion condition there were 100 trials, with 80 related and 20 unrelated trials in the .80 condition (i.e., most of the time the target came from the prime category), 50 related and 50 unrelated trials in the .50 condition (the target was equally likely to come from the category of the prime as the other category), and 20 related and 80 unrelated trials in the .20 condition (i.e., most of the time the target came from the other prime category).

### *Procedure*

The testing session including consent, screening, and the computer task lasted approximately 1.5 h. The three relatedness proportion conditions (.80, .50, and .20) were presented in separate blocks, and the order of block presentation was counterbalanced across participants. The prime words (TREE and ANIMAL) and target words were presented equally often at each level of relatedness and relatedness proportion. For each block, participants first completed 20 practice trials followed by 100 test trials. The practice trials maintained the same relatedness proportion as the test block (e.g., 16 related and 4 unrelated trials in the .80 condition, 10 related and 10 unrelated trials in the .50 condition, and 4 related and 16 unrelated trials in the .20 condition). During the practice trials participants received accuracy feedback (the words 'correct' or 'incorrect' in the center of the computer screen) to ensure that they understood the task. Feedback was not given during the test trials.

The trial sequence is outlined in Figure 1. A trial began with a fixation cross presented for 1000 ms and replaced by two white boxes that stayed on the screen for the remainder of the trial. After 1000 ms, the prime stimulus (ANIMAL or TREE) appeared in the top box for 150 ms and was followed 650 ms later by a target word presented in the bottom box. Participants pressed one of two labeled buttons to indicate the category of the target – the left button for tree and the right button for animal. The target remained on the screen until participants made a response.

Before each block the experimenter explained the task to participants using verbal instructions and a drawn representation of stimulus events. Participants were told that they should pay attention to the first (prime) word but not to respond to it. In the .80 condition participants were told that most of the time the first word would be followed by a word from that category (e.g., if the first word was ANIMAL, most of the time the second word would be an example of an animal, and if the first word was TREE, most of



the time the second word would be an example of a tree). In the .50 condition participants were informed that the second word was just as likely to come from either category, and in the .20 condition participants were told that most of the time the first word would be followed by a word from the other category (e.g., if the first word was ANIMAL, most of the time the second word would be an example of a tree, and if the first word was TREE, most of the time the second word would be an example of an animal). Participants were told that using this information would help them categorize the second word (the target) more quickly. They were also told to respond as quickly as possible but not at the expense of accuracy. Experimenters encouraged participants to take short rests between blocks.

## Results

Reaction time (RT) values that were less than 150 ms or more than 2000 ms were considered outliers and removed, as were individual RTs that were more than 2.5 standard deviations away from the participant's condition mean. Only trials with accurate responses were included in the calculation of mean RT. Table 2 displays the mean RTs and error rates for Experiment 1. Mean RTs were submitted to a  $2 \times 2 \times 3$  mixed analysis of variance (ANOVA) with age group (younger adults and older adults) as the between-subjects factor and prime–target relation (related and unrelated) and relatedness proportion (.80, .50, and .20) as the within-subjects factors. The only

**TABLE 2.** Mean RTs (ms) and error rates (%) for Experiment 1

	Experiment 1					
	Younger adults			Older adults		
	Relatedness proportion					
RT means	<u>.80</u>	<u>.50</u>	<u>.20</u>	<u>.80</u>	<u>.50</u>	<u>.20</u>
Related	572	579	602	577	608	639
Unrelated	614	580	585	623	615	617
U-R	42*	1	-17*	46*	7	-22*
RT SDs	<u>.80</u>	<u>.50</u>	<u>.20</u>	<u>.80</u>	<u>.50</u>	<u>.20</u>
Related	153	117	123	112	106	126
Unrelated	143	104	113	133	107	113
U-R	88	50	47	70	29	45
Errors	<u>.80</u>	<u>.50</u>	<u>.20</u>	<u>.80</u>	<u>.50</u>	<u>.20</u>
Related	2.6	1.9	1.5	0.7	0.8	1.0
Unrelated	1.5	1.4	5.4	2.5	1.1	0.6
U-R	-1.1	-0.5	3.9	1.8	0.3	-0.4

*Note:* RT, reaction time; U-R, unrelated RT minus related RT (mean difference score).  
\*Indicates that the difference score was significantly different from 0 by *t*-test,  $p < .05$ .

main effect was prime–target relation,  $F(1, 70) = 4.59$ ,  $p < .05$ . Participants were faster in the related condition than in the unrelated condition (596 vs. 606 ms, respectively). In addition, there was a significant two-way interaction between prime–target relation and relatedness proportion,  $F(2, 140) = 26.55$ ,  $p < .0001$ .

To explore the interaction, relatedness effects were explored within each relatedness proportion condition. In the .80 condition, participants had faster RTs on related trials as compared to unrelated trials (574 vs. 619 ms, respectively),  $F(1, 71) = 23.29$ ,  $p < .0001$ . In the .50 condition, RTs did not differ between related and unrelated trials (593 vs. 597 ms, respectively),  $F(1, 70) = 0.40$ ,  $p > .50$ . Finally, in the .20 condition participants had slower RTs on related trials as compared to unrelated trials (621 vs. 601 ms, respectively),  $F(1, 71) = 13.48$ ,  $p < .001$ . The absence of a significant three-way interaction,  $F(2, 140) = 0.18$ ,  $p > .80$ , indicated that older and younger adults did not differ significantly in the direction or magnitude of the relatedness effects. In fact, difference scores reflecting relatedness effects (unrelated RT minus related RT) were very similar for the two age groups (see Table 2).

Error rates for the test trials were low for each age group (2.4% for younger adults, 1.1% for older adults), so no further analyses were conducted on these data.

Because evidence of expectancies was observed in the performance of both younger and older adults, we analyzed the practice data to determine whether this pattern could be observed within the first 20 trials. The statistical significance patterns on the RT data were the same as those described for

the test trials, including a main effect of prime–target relation,  $F(1, 70) = 10.26$ ,  $p < .05$ , with faster responses in the related condition than in the unrelated condition (660 vs. 688 ms, respectively). In addition, there was a significant two-way interaction between prime–target relation and relatedness proportion,  $F(2, 140) = 27.35$ ,  $p < .0001$ , again reflecting faster RTs on related trials than on unrelated trials (605 vs. 725 ms, respectively) in the .80 condition and slower RTs on related trials than on unrelated trials (702 vs. 652 ms, respectively) in the .20 condition. In contrast to the test trials, the group main effect was significant for the practice trials,  $F(1, 70) = 5.59$ ,  $p < .05$ , with older adults responding more slowly overall than younger adults (713 vs. 636 ms, respectively). Overall error rates on practice trials were 3.5% for younger adults and 3.4% for older adults. There was a prime–target relation by relatedness proportion interaction,  $F(2, 140) = 9.71$ ,  $p < .0001$ , due to greater errors on unrelated trials (7.3%) than on related trials (1.9%) in the .80 condition, and greater errors on related trials (5.2%) than on unrelated trials (2.4%) in the .20 condition,  $F(1, 71) = 4.55$ ,  $p < .05$ .

## Discussion

The latency performance of both younger adults and older adults reflected the relevant relatedness proportions between the prime and target. Consistent with an anticipatory strategy, participants responded more quickly to related targets than to unrelated targets when related targets were more probable (.80 condition), and they responded more quickly to unrelated targets than to related targets when unrelated targets were more probable (.20 condition). There were no relatedness effects when related targets and unrelated targets were equally likely (.50 condition), suggesting that automatic semantic priming had little effect on performance at this prime–target interval. That being said, the absolute value of the relatedness effects were much greater when targets were mostly related (45 ms) than when targets were mostly unrelated (–20 ms), suggesting that learned semantic associations between stimuli impacted performance positively. (The discrepancy in relatedness effects for the .20 and .80 conditions is discussed further in the General Discussion.)

Analyses of the practice data indicated that participants likely used the information provided within the instructions (that most of the time the prime and target would be related or unrelated) to guide their response strategy on the task. Within the first 20 trials, participants were faster and more accurate on related trials than on unrelated trials when related trials were more probable, and they were faster and more accurate on unrelated trials than on related trials when unrelated trials were more probable. The absence of an age interaction for either the error or latency analyses suggests that older adults were as able as younger adults to use probability information conveyed through the instructions to flexibly formulate strategies for anticipating the target.

To summarize, there was no evidence for age differences in controlled expectancy effects. Older adults were as able as younger adults to adjust their attentional expectancies based on the instructions and proportion manipulations. Older adults' expectancies for a particular target category were reflected in performance quickly (within the first 20 practice trials) and were of similar magnitude to those of younger adults. Thus, older adults used contextual information at more than one level. They used the instructions preceding a trial block and the relatedness proportion information contained within a trial block to form a general expectancy across trials (for related or unrelated targets). In addition, trial to trial, older adults used the semantic information contained within a prime to prepare a specific response (tree or animal) based on the more general expectancy. Even under conditions that required fluid adjustment of controlled expectancies (mostly related for one block, mostly unrelated for another block), older adults were able to utilize controlled expectancies for semantic information.

## EXPERIMENT 2

The findings from Experiment 1 suggested that older adults could flexibly form controlled expectancies to match the semantic context. Next we considered whether the timing by which expectancies impacted behavior differed for younger and older adults. In Experiment 1, controlled expectancies were assessed at a prime–target SOA of 800 ms, an interval at which participants had time to process the prime information and prepare a context-appropriate response. However, automatic activation tends to dominate performance at shorter prime–target intervals (e.g., under 400 ms; Neely, 1977, 1991). Although expectancies were reflected in the performance of older adults by 800 ms, this age group may have been slower to prepare expectancy-consistent responses. To examine this possibility, younger adults and older adults completed a modified version of the Experiment 1 task. Participants completed the .20 condition (most of the time the prime and the target were unrelated) at prime–target SOAs of 100, 200, 500, and 800 ms.

We anticipated that at the shortest prime–target SOA (100 ms), the responses of both younger and older adults would be driven primarily by automatic priming. Although the participants would be instructed that most of the time the prime and target would be unrelated, they would not have time to prepare a response consistent with this expectancy. Thus, participants would be faster to categorize related targets than unrelated targets, due to automatic spreading activation within the semantic network. As the prime–target interval lengthened, we predicted that performance would decreasingly reflect automatic priming, which tends to be short lived, and increasingly reflect controlled expectancies, which need time to influence behavior. As a result, there would be a shift from faster responses to related

targets to faster responses to unrelated targets. If older adults were slower to make use of controlled expectancies, this shift would occur at a later time interval for this group.

## **Method**

### ***Participants***

Thirty-four younger adults (21 women, 13 men) in the age range of 18–29 years and 34 older adults (20 women, 14 men) in the age range of 60–78 years were tested and included in the data analysis for Experiment 2. Participants' screening and psychometric data are reported in Table 1. Participants were recruited and screened using the same approach that was described in Experiment 1, although none of the participants from Experiment 2 took part in Experiment 1. As found in the previous experiment, younger adults had significantly better visual acuity than older adults, whereas older adults scored significantly better than younger adults on the WASI vocabulary measure and had more years of education.

### ***Materials and Procedure***

The materials, stimuli, and procedures were the same as those described in Experiment 1, except we used one relatedness proportion condition (.20) and four prime–target SOAs (100, 200, 500, and 800 ms). As depicted in Figure 1, the prime word (ANIMAL or TREE) was presented for 100 ms and was followed after a 0, 100, 400, or 700 ms interstimulus interval (ISI) by a target word that was an example of an animal or a tree. Participants were told that they should pay attention to the first word because it would help them respond more quickly to the second word; if the first word was ANIMAL, most of the time the second word would be an example of a tree, and if the first word was TREE, most of the time the second word would be an example of an animal. Participants were instructed to categorize the target word as an animal or a tree by pressing one of two buttons as quickly as possible. After completing 20 practice trials (16 unrelated trials and 4 related trials) with accuracy feedback, participants completed six blocks of 80 trials (64 unrelated trials and 16 related trials per block) without accuracy feedback, for a total of 480 test trials. The prime words and target words were presented equally often for each relatedness condition and SOA. The SOAs were distributed equally across trial types and were randomly presented within each block.

## **Results**

Mean RTs and error rates are displayed in Table 3. Outlier RTs were identified and removed in the same manner as described in Experiment 1. Mean RTs for correct trials were submitted to a  $2 \times 2 \times 4$  mixed ANOVA with



**TABLE 3.** Mean RTs (ms) and error rates (%) for Experiments 2 and 3

	SOAs (ms)							
	Younger adults				Older adults			
Experiment 2 (.20 relatedness)								
RT means	<u>100</u>	<u>200</u>	<u>500</u>	<u>800</u>	<u>100</u>	<u>200</u>	<u>500</u>	<u>800</u>
Related	566	558	536	524	638	618	597	596
Unrelated	581	549	520	505	647	628	596	581
U-R	15*	-9	-16*	-19*	9*	10*	-1	-15*
RT SDs	<u>100</u>	<u>200</u>	<u>500</u>	<u>800</u>	<u>100</u>	<u>200</u>	<u>500</u>	<u>800</u>
Related	75	73	68	65	93	92	86	90
Unrelated	74	68	71	71	85	85	86	78
U-R	35	29	44	36	27	25	25	30
Errors	<u>100</u>	<u>200</u>	<u>500</u>	<u>800</u>	<u>100</u>	<u>200</u>	<u>500</u>	<u>800</u>
Related	4.6	5.1	4.4	4.2	1.5	1.3	1.2	1.7
Unrelated	4.4	4.0	2.8	2.3	1.6	1.2	1.1	1.3
U-R	-0.2	-1.1	-1.6	-1.9	0.1	-0.1	-0.1	-0.4
Experiment 3 (.80 relatedness)								
RT means	<u>100</u>	<u>200</u>	<u>500</u>	<u>800</u>	<u>100</u>	<u>200</u>	<u>500</u>	<u>800</u>
Related	619	590	555	543	690	673	612	612
Unrelated	692	639	624	600	757	737	682	665
U-R	73*	49*	69*	57*	67*	64*	70*	53*
RT SDs	<u>100</u>	<u>200</u>	<u>500</u>	<u>800</u>	<u>100</u>	<u>200</u>	<u>500</u>	<u>800</u>
Related	133	132	142	133	117	117	108	100
Unrelated	151	130	135	146	148	138	121	113
U-R	66	68	62	51	76	54	62	62
Errors	<u>100</u>	<u>200</u>	<u>500</u>	<u>800</u>	<u>100</u>	<u>200</u>	<u>500</u>	<u>800</u>
Related	1.9	2.2	2.1	2.0	0.9	0.8	0.9	0.8
Unrelated	5.6	10.2	5.9	5.5	2.8	2.8	1.8	1.4
U-R	3.7	8.0	3.8	3.5	1.9	2.0	0.9	0.6

Note: RT, reaction time; SOA, stimulus onset asynchrony between the prime and the target; U-R, unrelated RT minus related RT (mean difference score).

\*Indicates that the difference score was significantly different from zero by *t*-test,  $p < .05$ .

age group (younger and older adults) as the between-subjects factor and prime–target relation (related and unrelated) and prime–target SOA (100, 200, 500, and 800 ms) as the within-subjects factors. There were two significant main effects: age group,  $F(1, 66) = 15.02$ ,  $p < .001$ , and SOA,  $F(3, 198) = 73.04$ ,  $p < .0001$ . Older adults were slower to respond than younger adults (613 vs. 542 ms, respectively), and as SOA increased, RTs decreased (608, 588, 562, and 552 ms for SOAs of 100, 200, 500, and 800 ms, respectively). In addition, there was a significant two-way interaction of prime–target relation and SOA,  $F(3, 198) = 12.94$ ,  $p < .0001$ , reflecting a change in relatedness effects across prime–target SOAs. At the shortest SOA (100 ms), participants responded significantly faster to related targets than to unrelated targets (by 12 ms),  $F(1, 67) = 10.46$ ,  $p < .01$ , consistent with automatic activation.

By the longest SOA (800 ms), participants responded significantly faster to unrelated targets than to related targets (by 17 ms),  $F(1, 67) = 18.74$ ,  $p < .0001$ , consistent with controlled expectancies. The relatedness effect was not significant at 200 ms,  $p > .80$ , but it was marginally significant at 500 ms (with faster responses to unrelated targets than to related targets by 8 ms),  $F(1, 67) = 3.63$ ,  $p = .06$ . Importantly, a three-way interaction of age group  $\times$  prime–target relation  $\times$  SOA,  $F(3, 198) = 2.73$ ,  $p < .05$ , suggested that the time course by which controlled expectancy effects influenced behavior differed with age.

To explore the three-way interaction, we conducted separate prime–target relation  $\times$  SOA ANOVAs for each age group. For both younger adults,  $F(3, 99) = 47.00$ ,  $p < .0001$ , and older adults,  $F(3, 99) = 29.43$ ,  $p < .0001$ , there was a significant effect of SOA. The effect of prime–target relation was not significant for either age group, although the effect was marginal for younger adults,  $F(1, 33) = 2.99$ ,  $p = .09$ , with slower responses to related trials than to unrelated trials. The two-way interaction was significant for both younger adults,  $F(3, 99) = 8.29$ ,  $p < .0001$ , and older adults,  $F(3, 99) = 7.15$ ,  $p < .001$ . We calculated relatedness effects (unrelated RT minus related RT) for each participant. A positive number was consistent with automatic activation (faster responses to related targets than to unrelated targets) and a negative number was consistent with controlled expectancies (faster responses to unrelated targets than to related targets). Difference scores reflecting relatedness effects are reported in Table 3.

Younger adults showed a positive relatedness effect consistent with automatic activation at the 100 ms SOA,  $t(33) = 2.58$ ,  $p < .05$ , but at the 200 ms SOA, the relatedness effect was not significantly different from zero,  $p > .05$ . At the 500- and 800-ms SOAs, younger adults showed negative relatedness effects consistent with controlled expectancies,  $t$  values(33) =  $-2.17$  and  $-3.04$ , respectively,  $p$  values  $< .05$ . A one-way ANOVA on relatedness effects revealed a significant effect of SOA for younger adults,  $F(3, 99) = 47.00$ ,  $p < .0001$ . The 100-ms relatedness effect differed significantly from the effect at each of the three longer SOAs. For older adults, positive relatedness effects (effects significantly greater than zero) were evident at the two shorter SOAs (100 and 200 ms),  $t$  values  $> 2.0$ ,  $p$  values  $< .05$ . Relatedness effect did not differ from zero at the 500-ms SOA. At the 800 ms SOA, the relatedness effect for older adults was significantly less than zero,  $t(33) = -3.07$ ,  $p < .01$ . When relatedness effects were submitted to a one-way ANOVA, older adults showed a significant effect of SOA,  $F(3, 99) = 29.43$ ,  $p < .0001$ . The 800-ms relatedness effect differed significantly from the effect at each of the three shorter SOAs.

To analyze age differences in the pattern of relatedness effects, one-way ANOVAs on relatedness difference scores were conducted at each SOA. Age effects were significant at the 200-ms SOA,  $F(1, 66) = 7.80$ ,  $p < .01$ , with

greater relatedness effects for older adults than for younger adults. Age effects at the 500-ms SOA were marginally significant,  $F(1, 66)=3.39$ ,  $p=.07$ , with older adults showing slightly greater relatedness effects than younger adults. For the 100- and 800-ms SOAs, there was not a significant effect of group, with both age groups demonstrating similar magnitudes of positive relatedness effects at 100 ms (consistent with automatic activation) and negative relatedness effects at 800 ms (consistent with controlled expectancies).

Because error rates were low for each age group (4.0% for younger adults, 1.3% for older adults), no further analyses were conducted on error data.

## Discussion

On a task in which the target word was most likely to come from a category unrelated to the prime word, performance was consistent with automatic activation at the shortest prime–target interval (100 ms), in terms of faster categorization of related targets than of unrelated targets. By the longest prime–target interval of 800 ms (the same SOA that was used in Experiment 1), performance was consistent with controlled expectancies, in terms of faster categorization of unrelated (but expected) targets than related (but unexpected) targets. Performance did not vary with age at the shortest and longest SOAs, instead, younger adults and older adults both appeared to show similar patterns of automatic activation at the early interval and controlled expectancies at the later interval. However, performance for the mid-range SOAs suggested age-related slowing in the realization of expectancies in behavior. At the 200-ms SOA, older adults continued to show positive relatedness effects (automatic activation), whereas younger adults began to show negative (although not yet significant) relatedness effects (controlled expectancies). At 500 ms, a relatedness effect consistent with controlled expectancies was significant for younger adults but had not yet appeared for older adults.

As predicted, the relative involvement of automatic activation and controlled expectancy processes determined the effect of context on categorization behavior. Relatedness effects could be reversed depending on the temporal interval between the prime and target, and this was true for both younger and older adults. Also as predicted, a delayed appearance of negative relatedness effects suggested that, for older adults, controlled expectancies were slower to influence categorization behavior, although by 800 ms, expectancy effects were similar for younger and older adults. It is possible that a need to shift attention from the prime category to an unrelated category led to the age-related delay in expectancy-consistent responses. In fact, in the spatial domain, older adults can be slower to disengage and shift attention between locations (Castel et al., 2003) particularly when the shifts are based on symbolic

cues (e.g., central arrows) and the task requires discriminating between stimuli (Greenwood, Parasuraman, & Haxby, 1993; Juola, Koshino, Waner, McMickell, & Peterson, 2000). It is possible that older adults could have similar difficulties in efficiently shifting attention between semantic categories. Another possibility is that older adults may have been slower to anticipate an unrelated target because of the greater processing resources required when the context–target pairings were not based on pre-existing semantic relationships. Thus, the same age-related changes in expectancy timing may not be observed on a task in which the expectancy is for information semantically related to the context.

### EXPERIMENT 3

The purpose of Experiment 3 was to determine whether the age differences in the temporal pattern of relatedness effects that was observed in Experiment 2 would exist when the controlled expectancy was for a target word that was semantically related to the prime. We used the semantic priming task from Experiment 2 but this time with the .80 relatedness proportion. With a .20 relatedness proportion, automatic activation and controlled expectancies led to opposite response biases (faster responses to related targets with automatic activation, faster responses to unrelated targets with controlled expectancies). With a .80 relatedness probability, automatic activation and controlled expectancies would both lead to faster responses on the related trials as compared to the unrelated trials. Because automatic activation effects are short lived (e.g., 400 ms) and do not have a strong influence on performance at later prime–target intervals (Burke et al., 1987; Neely, 1977), the positive relatedness pattern was hypothesized to be due primarily to automatic priming at the shorter prime–target intervals and to controlled expectancies at the longer intervals (Neely, 1977, 1991). As demonstrated in Experiment 1, if there is no expectancy for a related target to appear (as in the .50 condition), a pre-existing and well-learned association does not necessarily lead to an advantage in response times when performance is assessed at longer prime–target intervals (i.e., similar RTs were found for related and unrelated pairings in the .50 condition at 800 ms). Instead, the longer intervals provide sufficient time for controlled expectancies to be realized, as evidenced in Experiment 2.

Consistent with the findings of Experiment 2, we predicted that younger and older adults would have similar relatedness effects at the shortest and longest intervals. However, at the middle prime–target intervals, we predicted there to be some temporary drop-off in positive relatedness effects as automatic priming declined but controlled expectancies had not yet had a full impact on performance. Similar to Experiment 2, we expected this drop off would maintain longer for older adults than younger adults, consistent

with delayed expression of controlled expectancies. However, if expectancies could be developed more efficiently by older adults when a shift between semantic categories was not required, or with a more supportive semantic context, then older adults would show the same pattern of relatedness effects as younger adults.

## Method

### *Participants*

Thirty-two younger adults (20 women, 12 men) in the age range of 18–25 years and 32 older adults (21 women, 11 men) in the age range of 61–76 years were tested and included in the data analysis for Experiment 3. See Table 1 for participants' screening and psychometric data. Participants were recruited and screened in the same manner as described in the previous experiments, but none of the participants in Experiment 3 had taken part in Experiments 1 or 2. As in the previous experiments, younger adults had better visual acuity than older adults, whereas older adults scored better than younger adults on the WASI vocabulary measure and had more years of education.

### *Materials and Procedure*

The materials, stimuli, and procedures were the same as those used in Experiment 2 except that the relatedness proportion was changed to .80. The prime word (ANIMAL or TREE) was presented for 100 ms and was followed by a target word (an example of an animal or a tree) after an ISI of 0, 100, 400, or 700 ms (resulting in SOAs of 100, 200, 500, or 800 ms). Participants were told that most of the time the first word would be followed by a word from the same category (e.g., if the first word was ANIMAL, most of the time the second word would be an example of an animal, and if the first word was TREE, most of the time the second word would be an example of a tree). Participants were additionally told that they should pay attention to the first word because it would help them respond more quickly to the second word. After completing 20 practice trials (16 related trials and four unrelated trials) with accuracy feedback, participants completed 480 test trials without accuracy feedback; test trials were divided into six blocks of 80 trials (64 related trials and 16 unrelated trials per block).

## Results

Outlier RTs were identified and removed in the same manner as described in Experiment 1. Mean RTs and error rates are displayed in Table 3. The same  $2 \times 2 \times 4$  mixed ANOVA on mean RTs for correct trials that was used in Experiment 2 was applied to the present data, revealing all main effects to be significant: age group,  $F(1, 62) = 5.38, p < .05$ , prime–target relation,

$F(1, 62)=137.28, p < .0001$ , and SOA,  $F(3, 186)=87.70, p < .0001$ . Older adults were slower to respond than were younger adults (679 vs. 608 ms, respectively); responses overall were faster on related trials as compared to unrelated trials (612 vs. 675 ms, respectively), and as SOA increased, RT decreased (689, 660, 618, and 605 ms for SOAs of 100, 200, 500, and 800 ms, respectively). In addition to the main effects, there was a significant two-way interaction between age group and SOA,  $F(3, 186)=2.89, p < .05$ . Although the performance of younger adults,  $F(3, 93)=40.88, p < .0001$ , and older adults,  $F(3, 93)=49.23, p < .0001$ , reflected the same overall SOA pattern (decreasing RT with increasing SOA), older adults did not show a significant decrease in RT from 500 to 800 ms (647 vs. 639 ms, respectively). The absence of interactions involving prime–target relation indicated that relatedness effects remained relatively constant across SOAs and age groups. Difference scores reflecting relatedness effects (unrelated RT minus related RT) are presented in Table 3. Both younger adults and older adults displayed positive relatedness effects (62 vs. 63 ms, respectively) that did not vary significantly in magnitude across SOAs. In addition, there were no significant age differences in relatedness effects at any of the SOAs,  $p$  values  $> .30$ .

Errors were low for both age groups (4.4% for younger adults, 1.5% for older adults), thus no further analyses were conducted on error data.

## Discussion

On a task in which the target was most likely to come from the semantic category named by the prime, participants were faster to categorize related target words than unrelated words. We expected both automatic activation and controlled expectancy processes to be reflected in faster categorization of related targets than unrelated targets, and consistent with this prediction, we found significant positive relatedness effects both at the shortest SOA (100 ms), consistent with automatic activation, and at the longest SOA (800 ms), consistent with controlled expectancies. These effects did not vary with age, indicating that the performance of both younger adults and older adults reflected automatic and controlled semantic priming processes. In contrast to our predictions, we did not find any modulation in the magnitude of the relatedness effects at the middle SOAs (200 and 500 ms), which would be anticipated as automatic activation declined but anticipatory responses had not yet been prepared. Instead, relatedness effects remained steady across the prime–target temporal intervals.

What may account for this pattern? Because participants were expecting a semantically related target, preparing a response based on that expectancy did not require participants to shift attention from the presented category to a semantically unrelated category. As a result, participants (older adults as well as younger adults) may have prepared responses based on expectancies more efficiently than in Experiment 2, in which participants

*did* need to make such an attentional shift to prepare a response. If this was the case, then controlled expectancies could have been realized in behavior as automatic activation declined, maintaining relatedness effects at the middle prime–target intervals (200 and 500 ms). If the attentional shift across categories was particularly troublesome for older adults in Experiment 2, then task conditions that encouraged expectancies for semantically related information could have eliminated the age-related delay in the influence of expectancies observed in Experiment 2. (An alternative explanation for the discrepancy in age patterns across Experiments 2 and 3 is described in the General Discussion.) Together the evidence indicates that when the prime information was semantically related to the target information, older adults were as able as younger adults to efficiently use contextual information to influence their responses to target information.

## GENERAL DISCUSSION

The context processing theory of Braver et al. (2005) contends that older adults are less able to attend to contextual information proactively to anticipate future target information. Results from the present study were inconsistent with this theory. Contrary to findings from the AX-CPT task (Braver et al., 2001; Paxton et al., 2006; Rush et al., 2006), older adults could use context to predict target information on the semantic priming task without extended practice or strategy training. Instead, there was evidence of expectancies in older adults' behavior within the first 20 practice trials of Experiment 1, suggesting that older adults benefited from information presented in the instructions regarding likely prime–target pairings for guiding anticipatory strategies. In addition, older adults were able to flexibly adjust expectancies (e.g., switch from expectancies for related targets to expectancies for unrelated targets) as instructions and prime–target relatedness changed. Across three experiments we found that older adults could use the meaning of the prime and the likelihood that a prime and target were related to anticipate the semantic category of the target, consistent with findings from other semantic priming studies (Balota et al., 1992; Burke et al., 1987).

Although in Experiment 1 we found that younger adults and older adults were equally able to benefit from controlled expectancies by 800 ms following presentation of the prime word, in Experiment 2 we found some evidence that the time course by which controlled expectancies were realized in performance differed between younger and older adults. Using a relatedness proportion in which most of the time the target word came from a category semantically unrelated to the prime (.20), we replicated the finding from Experiment 1 in that both younger and older adults demonstrated evidence of controlled expectancies by 800 ms post-prime. However, we also found evidence that at shorter prime–target intervals, automatic activation had a longer

lasting influence on older adults' performance. Older adults continued to show automatic activation effects at an interval at which younger adults had already begun transitioning to controlled expectancy effects (200 ms), and younger adults showed fully developed controlled expectancy effects at an earlier interval than did older adults (500 vs. 800 ms).

A brief prime–target interval may leave older adults insufficient time to direct their attention based on expectancy information, particularly when their attention must shift from one category to another. Balota et al. (1992) found that older adults had more difficulty *maintaining* expectancies at longer prime–target intervals unless the prime information remained available during the interim. We found that older adults were slower to transform an expectancy into behavior, but only when the expectancy went against the natural semantic relationship. Together the findings support altered timing for controlled expectancies with age, with delayed utilization and reduced maintenance. The present age-related delay in shifting behavior is consistent with studies finding deficits in switching attention between mental sets or response sets (Hahn et al., 2004; Mayr & Liebscher, 2001) or shifting attention between locations (Greenwood et al., 1993; Juola et al., 2000). The longer duration of automatic activation effects on the part of older adults in Experiment 2 suggests that older adults may have been slower to disengage from the prime information as well (Castel et al., 2003).

When the task conditions encouraged expectancies for semantically related information (Experiment 3), age differences were not found in the timing by which expectancies influenced behavior. Relatedness effects were relatively constant in magnitude across prime–target SOAs, regardless of age, suggesting that there was a smooth transition from automatic activation to controlled expectancies for both younger and older adults. One possible reason for an age effect in the timing of expectancies in Experiment 2 but not in Experiment 3 is that expectancy generation in Experiment 3 did not require participants to shift attention to an unrelated category, as it did in Experiment 2. As a result, older adults may have used expectancies more efficiently, within the time allowed at the shorter prime–target intervals (e.g., 500 ms). The need to shift attention between categories may have influenced the *magnitude* as well as the timing of the expectancy effects. Relatedness effects were greater in Experiment 3 (.80 relatedness proportion) than in Experiment 2 (.20 relatedness proportion), perhaps because without a shift to a new category, an expectancy for a particular target category could be more fully expressed within the time elapsed before the target was presented. Replicating this pattern within an experiment, the absolute magnitude of the relatedness effects in Experiment 1 for the .80 condition was approximately twice the magnitude of the effects for the .20 condition. Thus, generating expectancies for unrelated information may have more heavily taxed attentional systems, particularly for older adults.



There is an alternative explanation for the difference in magnitude of the relatedness effects for the .80 and .20 conditions (as observed within Experiment 1 and between Experiments 2 and 3). The magnitude difference was observed at the 100-ms SOA (relatedness effects of 70 ms in Experiment 3, 12 ms in Experiment 2) and at the 800-ms SOA (relatedness effects of 55 ms in Experiment 3, -17 ms in Experiment 2). This pattern suggests that the between-experiment manipulation of relatedness proportion had an overall effect that went beyond anticipated automatic priming and controlled expectancy effects. It is especially surprising to see an effect of relatedness proportion at 100 ms, a time interval at which the relatedness proportion is thought to have relatively little effect, because it is too short a time for conscious expectancies to influence behavior, and automatic priming is not traditionally thought to be influenced by relatedness proportion (Neely, 1977, 1991). In other words, with automatic activation, responses to a target should be faster when the target is semantically related to the prime (due to spreading activation within the semantic network) regardless of the proportion of trials in which the prime and target are related. If the proportion of related trials influenced relatedness effects at this early interval, then some other process was likely involved.

Bodner and Masson (2003, Experiment 1) found a similar pattern as described above, with increasing semantic priming effects with an increased relatedness proportion at an SOA as short as 45 ms. They argued that the higher the prime validity (the higher the proportion of trials in a block in which primes were related to their targets), the more participants made use of primes to aid in identifying targets. Because this effect occurred when primes were masked and not consciously recalled, and at very brief prime-target intervals, Bodner and Masson argued that this prime-recruitment process was automatic and separate from a conscious expectancy-generation strategy. In contrast to the prospective nature of expectancies, the authors described the prime recruitment process as retrospective, activated upon target presentation. Because participants implicitly encoded the pattern of strong prime validity across trials, they began to episodically retrieve the prime upon target presentation, which facilitated target identification (see also Stolz, Besner, & Carr, 2005). So instead of using context to anticipate future outcomes, participants episodically retrieved context upon presentation of target information.

The task conditions of Experiment 3 (.80 relatedness probability) may have set the stage for this additional context-sensitive process to become involved. With awareness of the high proportion of related trials within a block, participants may have automatically retrieved the prime information upon target presentation, which would have facilitated response selection (particularly because the prime matched the target response on most trials). The prime recruitment process would have had little influence on performance

in Experiment 2, in which only a low proportion (.20) of trials was related. (A similar argument can be made for the contrasting pattern of results in the .80 and .20 relatedness conditions of Experiment 1.)

Because the operation of prime episode retrieval is not tied to SOA, as controlled expectancies are, this may explain the greater relatedness effects in Experiment 3 as compared to Experiment 2 at all SOAs. The presence of an age effect in Experiment 2 but not in Experiment 3 may have been explained by prime-recruitment processes that contributed to performance in Experiment 3 but not in Experiment 2, which modified or overshadowed the age differences in controlled expectancies. This general automatic process of post-target prime recruitment, which is still considered a process resulting from context processing, could be relatively insensitive to age effects. There is some evidence from the AX-CPT task that older adults are more likely than younger adults to make use of retroactive processing of prime information, particularly when controlled expectancies have a reduced influence on performance (Braver et al., 2005). Whether the lack of age differences in the magnitude of relatedness effects in the .80 condition was due to additional automatic context processes or reduced expectancy-related switching costs, it is important to note that this effect was similar for younger adults and older adults, suggesting that these context processes were not impacted by age.

Under conditions in which prime episode retrieval was unlikely (i.e., when the prime word predicted that the target word would come from an unrelated category), older adults were able to use context to anticipate the semantic meaning of the target word. In the first experiment, older adults could form and quickly adjust controlled expectancies to reflect the current prime–target relationships, even when the expectancy was for unrelated words. In the second experiment, older adults could use expectancies to prepare a target response, but not as rapidly as younger adults. Thus, when expecting the target to come from a category unrelated to the prime word, it appeared that older adults either disengaged from the prime word more slowly or switched attention from the prime category to the unrelated category less efficiently. Another possibility is that a general age-related reduction in processing efficiency impacted the speed with which the target category was anticipated (Hale & Myerson, 1995; Myerson, Hale, & Chen, 1997). Without the aide of automatic semantic processes (semantic activation or prime recruitment), this age-related slowing in controlled attentional deployment could be revealed. Consistent with the present findings, studies that have examined the influence of sentence context on processing of word meaning (Dagerman, MacDonald, & Harm, 2006; Federmeier & Kutas, 2005) have found older adults to be less able to rapidly use sentence context to disambiguate word meaning, with some indication that reduced processing efficiency contributed to the age-related changes in context use.

What may account for the different conclusions regarding age differences in attention to context as assessed by the semantic priming task and the AX-CPT task? Although the two tasks differ in many respects, there is certainly overlap in the cognitive processes that are assessed. In both tasks, participants benefit in their overall speed and accuracy if they use presented contextual information (a cue letter in the case of the AX-CPT task, a prime word in the case of the semantic priming task) to anticipate the identity or category membership of the upcoming target information. In both tasks, participants must match the overall expectancy circumstances of the task (the likelihood that a particular target will be presented given a particular prime) with the current contextual information (the prime that is currently presented) to prepare the appropriate response. Although in both cases particular pairings are highly likely (e.g., X is likely to follow A in the AX-CPT task, the prime and target are likely to be semantically related), only in the instructions to the semantic priming task is this relationship explicitly detailed. This instructional difference may account in part for the different age patterns observed on the two tasks. In this study and other semantic priming studies in which the prime–target relationship was highlighted in the instructions (Balota et al., 1992; Burke et al., 1987), there was evidence that older adults used an anticipatory strategy in responding. When instructions did not detail the likely cue–target pairing in the AX-CPT task, older adults did not use the cue information in a proactive manner (e.g., Braver et al., 2001; Paxton et al., 2006). The present study further demonstrated that expectancies influenced older adults' performance as early as the first 20 practice trials (Experiment 1), firmly suggesting that older adults acted upon the prime–target pairings as detailed in the instructions to form a response strategy. Taking into consideration that Paxton et al. (2006) found improvement in older adults' performance on the AX-CPT task when strategy training detailed the proportion information across trials, the present findings suggest that older adults may have difficulties specific to detecting the cue–probe probability relationship across trials when it is not explicitly stated.

Another key difference between the semantic priming task and the AX-CPT task is the use of well-established semantic relationships in the former task and novel pairings in the latter task. The novel nature of the letter pairing in the AX-CPT task may have contributed to the difficulty older adults had using the prime letter to anticipate the identity of the target letter (Braver et al., 2001, 2005; Paxton et al., 2006; Rush et al., 2006). In contrast, we found in the present study that given sufficient time on the semantic priming task, older adults could use both novel and established prime–target pairings to anticipate the likely category of the target word given the prime word. An important distinction between the novel pairing used in the AX-CPT task (pairing random letters) and the novel pairing used in the semantic priming task is that participants completing the semantic priming task could use

pre-existing category knowledge to facilitate integration of the novel prime–target relationships. For example, when the prime word ‘TREE’ was most likely to be followed by a word from the animal category, participants could access their pre-existing knowledge of animal exemplars in anticipation of the target word. Consistent with a novel–familiar distinction, older participants in Experiment 2 were slower than their younger counterparts to use expectancy information when the expectancy was for an unrelated prime–target pairing. When participants expected primes and targets to be semantically related (Experiment 3), the time course of anticipatory responding did not differ between younger and older adults. This novel–familiar pattern parallels age patterns observed in the memory literature (Craig, 1994; Craig et al., 1987; Park et al., 1990; Smith et al., 1998). Craig and Jennings (1992) argued that if the contextual information is integrated with the target information, older adults can use context similarly to younger adults to retrieve target information. However, if contextual cues and targets are not well integrated by pre-existing associations (thus requiring greater processing resources for retrieval), then age differences in memory should be magnified. Findings from the present study suggest that integration processes also impacted expectancy use, with facilitated response preparation under established semantic conditions.

This study conceptualized context at more than one level. Context was created with the prime–target pairings across trials (mostly related or mostly unrelated) and the instructions detailing these relationships. In addition, the presented prime served as the context for that trial. Both younger adults and older adults were able to consider context at both levels to anticipate the target. With more novel prime–target pairings, older adults were slower to anticipate the target based on the contextual information. In line with the environmental support and integration hypotheses proposed for memory performance, we found that older adults could take advantage of a supportive context, particularly when it was semantically meaningful, to facilitate attention to word meanings (Craig, 1994; Craig et al., 1987; Park et al., 1990; Smith et al., 1998).

In sum, the current set of findings indicate that, in contrast to findings from the AX-CPT task (Braver et al., 2001; Paxton et al., 2006; Rush et al., 2006), older adults are indeed able to form and benefit from controlled expectancies for upcoming information. The ability to proactively guide attention toward anticipated outcomes enhanced the performance of both younger and older adults, even under conditions in which the expectancies needed to be demonstrated within a limited number of trials and then adjusted as the relationship between the prime and target changed. Even when responding to novel associations between semantic categories, older adults were able to anticipate information from an unrelated category. The other important finding from this study is that the time course by which

controlled expectancies benefited performance may have changed with age, such that older adults needed more time than younger adults to process the context and direct attention accordingly, but only when the expectancy was for information semantically unique from the context. This age-related slowing may have reflected the less automatic nature of the prime–target association (requiring more self-initiated processing) or difficulty disengaging and shifting attention between semantic categories.

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