

# Effects of Bilingualism, Aging, and Semantic Relatedness on Memory Under Divided Attention

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**Abstract** We examined how encoding and retrieval processes were affected by manipulations of attention, and whether the degree of semantic relatedness between words in the memory and distracting task modulated these effects. We also considered age and bilingual status as mediating factors. Monolingual and bilingual younger and older adults studied a list of words from a single semantic category presented auditorily, and later free recalled them aloud. During either study or retrieval, participants concurrently performed a distracting task requiring size decisions to words from either the same or a different semantic category as the words in the memory task. The greatest disruptions of memory from divided attention (DA) were for encoding rather than retrieval. The effect of semantic relatedness was significant only for DA at encoding. Older age and bilingualism were associated with lower recall scores in all conditions, but these factors did not influence the magnitude of memory interference. The results suggest that encoding is more sensitive to semantic similarity in a distracting task than is retrieval. The role of attention at encoding and retrieval is discussed.

**Résumé** Nous avons examiné comment les processus d'encodage et de récupération étaient influencés par les manipulations de l'attention et si le niveau de relation sémantique entre les mots en mémoire et la tâche de distraction modulait ces effets. Nous avons également considéré l'âge et le bilinguisme comme des facteurs médiateurs. Des adultes plus jeunes et plus âgés unilingues et bilingues ont étudié une liste de mots d'une seule catégorie sémantique présentée de façon auditive et les ont prononcés plus tard à haute voix. Pendant la période d'étude ou de récupération, les participants ont exécuté en même temps une tâche de distraction demandant que les décisions de taille par rapport aux mots soit de la même catégorie sémantique ou d'une catégorie différente que les mots dans la tâche de mémoire. Les désordres les plus grands de la mémoire causés par l'attention divisée (AD) étaient pour l'encodage

plutôt que la récupération. L'effet de la relation sémantique était important seulement pour l'AD à l'encodage. L'âge plus avancé et le bilinguisme étaient associés à des évaluations de rappel plus faibles dans toutes les conditions, mais ces facteurs n'influençaient pas l'importance de l'interférence de la mémoire. Les résultats suggèrent que l'encodage est plus sensible que la récupération à la sensibilité sémantique dans une tâche de distraction. Le rôle de l'attention à l'encodage et la récupération fait l'objet de discussions.

Recent studies of bilingualism have shown that bilingual children and adults demonstrate enhanced attentional control in a variety of tasks involving perceptual or response conflict (Bialystok, 2001; Bialystok, Craik, Klein, & Viswanathan, 2004). This bilingual processing advantage is not confined to linguistic tasks but has been found in a variety of simple experimental paradigms such as the dimensional change card sort task (Bialystok & Martin, 2004), the ability to see the alternate image in a reversible figure (Bialystok & Shapero, 2005), and the Simon task (Bialystok et al., 2004). In a typical Simon task, coloured patches are presented to the right or left of a screen, above right and left response keys. The experimental rule may be "if the patch is red press left, if green press right," and the stimulus patch is then presented either above the appropriate key (congruent response) or the inappropriate key (incongruent response). The general finding is that incongruent stimulus-response pairs are associated with longer response times than congruent pairs (the "Simon effect"), and it is argued that smaller Simon effect values indicate better cognitive control (Lu & Proctor, 1995). The finding that bilingual children (Martin-Rhee & Bialystok, submitted) and adults (Bialystok et al., 2004) have smaller Simon effects than their monolingual peers has thus been taken as evi-

dence that bilingualism induces the development and maintenance of more efficient attentional control.

The exact nature of this superior control, however, is still a matter of debate. Green (1998) proposed a model of cognitive functioning in bilingual individuals in which the language that is not in current use is suppressed by the same executive functions used generally to control attention and inhibition. Given that bilinguals have had massive practice throughout their lives in exercising such control processes, they may experience a boost in such functions that generalizes across tasks. Other recent work has suggested that "inhibitory control" is not a unitary construct but comprises a variety of attentional functions, among them interference suppression and response inhibition (Bunge, Dudukovic, Thomason, Vaidya, & Gabrieli, 2002). Interference suppression is the ability to avoid attending to misleading information (as in the misleading spatial information in the Simon task) and response inhibition is the ability to withhold an inappropriate but habitual response. Martin-Rhee and Bialystok (submitted) have shown that the bilingual advantage is confined to interference suppression; that is, bilingual individuals are better able to ignore salient but irrelevant cues. One further set of findings in the bilingual literature is that the bilingual advantage is strong in children, declines to a relatively small effect in older children and young adults, but then reappears strongly in older adults (Bialystok, 2001; Bialystok et al., 2004; Bialystok, Craik, & Ryan, *in press*). The suggestion is that bilingualism accelerates the development of cognitive control in young children and serves as a protective factor against cognitive decline in older adults.

One major purpose of the present study was to explore these interactive effects of aging and bilingualism in a dual-task memory paradigm. Previous studies have shown that when participants carry out a demanding secondary task while encoding words for a later memory test, subsequent memory performance is substantially impaired (Baddeley, Lewis, Eldridge, & Thomson, 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Murdock, 1965; Naveh-Benjamin, Craik, Guez, & Dori, 1998). Performing a secondary task during retrieval from memory has only a small effect on memory performance (Baddeley et al., 1984; Craik et al., 1996) unless the materials used in the secondary task overlap with the information used in the memory task (Fernandes & Moscovitch, 2000, 2002, 2003). Fernandes and Moscovitch (2000) suggested that retrieval depends on the reactivation of the content of memories, which is hampered only when there is similar material in the memory and secondary task competing for those same representations. Specifically, they showed that divided attention (DA) using a word-moni-

toring distracting task produced a decrement in memory of 30% from full attention, whereas an equally demanding digit-monitoring task led to a decrement of only 13%. This is in contrast to DA at encoding, in which both distracting tasks disrupted later memory, by about 50%. These findings suggest that attention plays a more critical role in determining memory performance during encoding than it does during retrieval. Further work by Fernandes and Moscovitch (2002) showed that the primary locus of interference from DA at retrieval is at the phonemic level. In that study, a distracting task involving semantic decisions about line drawings led to only moderate disruptions of memory retrieval, whereas a word-based distracting task involving phonological judgments to pronounceable non-words was associated with much greater amounts of memory interference.

The effects of aging on memory under dual-task conditions have also been studied extensively to investigate the role of attention in encoding and retrieval. While representational aspects of cognitive function are preserved with aging, those that depend on executive control show a marked decline. For example, vocabulary levels (Park, 2000; Salthouse, 1991), language use (Wingfield & Stine-Morrow, 2000), and general world knowledge (Salthouse, 1982) are unimpaired in older adults. However, tasks requiring selective attention or inhibition of unrelated stimuli are performed more poorly by older compared to younger healthy adults. It has been suggested that older adults have less effective attentional processes, which results in poorer detection, discrimination, and selection of task-relevant stimuli, and increased susceptibility to interference (McDowd & Shaw, 2000).

When a secondary task is performed during the encoding phase, the typical result is that the reduction in memory performance is equivalent in younger and older adults (Anderson, Craik, & Naveh-Benjamin, 1998; Nyberg, Nilsson, Olofsson, & Bäckman, 1997) although other studies have found that older adults are more susceptible than young adults to interference from DA at encoding (Park, Smith, Dudley, & Lafronza, 1989; Puglisi, Park, Smith, & Dudley, 1988). In contrast to encoding, most studies have found that older adults are no more susceptible to interference than are young adults when attention is divided during the retrieval stage (Anderson et al., 1998; Fernandes & Moscovitch, 2003; Fernandes, Davidson, Glisky, & Moscovitch, 2004; Macht & Buschke, 1983; Nyberg et al., 1997; Park et al., 1989; Whiting & Smith, 1997). Performance on the distracting task, however, tends to be disrupted more in older than in younger adults (Anderson et al., 1998; Craik & McDowd, 1987; Whiting & Smith, 1997), leading some (Anderson et al., 1998) to conclude that older

adults have a reduction in resources available to engage in demanding mnemonic operations (e.g., maintaining set, using strategies), as indexed by higher distracting task costs, but that the actual retrieval of information is relatively preserved. This work thus also suggests that general attentional resources play a more indirect role during retrieval than at encoding, and that recovery of the memory traces is less affected by manipulations of attention during retrieval than during encoding.

Given that memory encoding processes are greatly disrupted by performance of a secondary task, and that bilinguals are apparently better able to resist the effects of interfering events, we predicted that bilinguals would show smaller interference effects from divided attention (DA) at encoding on memory performance. With regard to retrieval, it seemed possible that the bilingual-monolingual contrast would mimic the young-old contrast, in the sense that bilinguals might show smaller secondary task costs than monolinguals, but show no difference in susceptibility to memory interference from attentional manipulations at retrieval. In the present study, a series of words from the same semantic category was presented auditorily and participants were required to recall these words for a subsequent memory test. The word list was either presented alone under conditions of full attention (FA), or concurrently with a visual classification task requiring a manual response (DA). The retrieval phase (spoken free recall of the words) was again undertaken either under FA or DA conditions. If bilingual speakers are better at resisting the effects of interference, they should show smaller "DA costs" in memory performance when the secondary task is performed at encoding. If the bilingual advantage reflects a general processing superiority, bilinguals should also show smaller DA costs in the secondary task when it is performed at retrieval. Finally, on the basis of previous results (Bialystok, Craik, & Ruocco, *in press*; Bialystok et al., 2004), these effects were expected to be larger in older adults.

In addition to attempting to clarify the nature of the bilingual advantage in cognitive control, a second purpose of the study was to gather further information on the differences between memory encoding and retrieval processes as revealed by the dual-task paradigm. The understanding at present is that encoding requires general processing resources, and so any manipulation diverting attention from encoding results in a later memory deficit regardless of the nature of the distracting task. In line with this, Fernandes and Moscovitch (2000) found substantial reductions in memory performance when participants had to carry out either a word-monitoring or a digit-monitoring task concurrently with encoding, and Craik et al. (1996)

found comparable drops in performance using a visual continuous reaction-time (RT) task. In contrast, the qualitative nature of the secondary task performed concurrently with retrieval appears to be crucially important; the level of retrieval performance is affected only slightly when the secondary task is qualitatively distinct from the material to be retrieved, but performance drops substantially when the secondary task involves similar processing operations to those needed for retrieval (Fernandes & Moscovitch, 2000, 2002, 2003). It thus seems that, counter to the suggestions of Craik (1983), Morris, Bransford, and Franks (1977), and Tulving and Thomson (1973), encoding and retrieval processes may differ in important ways, or at least be affected by different factors.

On the basis of their results, Fernandes and Moscovitch (2002) suggested that phonemic interference has the greatest disruptive effect on the retrieval of verbal material. Their study did not directly manipulate the degree of semantic relatedness between words in the memory and distracting task, however. It may be that variations in semantic relatedness between the words being retrieved and those in the distracting task modulate the size of memory interference at retrieval. Moreover, no study to date has investigated whether the semantic relatedness of materials used in concurrent tasks at *encoding* would also modulate the size of interference. The present study examines these possibilities.

In outline, the secondary task used in the experiment was one in which words were presented visually and the participant's task was to decide as rapidly as possible whether the word's referent object was bigger or smaller than some specified comparison object (e.g., the computer monitor). Semantic relatedness in the dual-task situation was manipulated by presenting words in the size judgment task either from the same semantic category as the words being encoded or retrieved in the memory test, or from a different semantic category. We assumed that higher levels of cognitive control would be required to perform the two concurrent tasks when memory and size judgments were in the same semantic domain. That is, keeping the two streams of words separate may require more attention when the words are semantically similar. This suggestion is in line with the finding that seniors, with reduced attentional resources, are more susceptible to false memories during recall of words that are semantically similar, than are younger adults (Norman & Schacter, 1997). Based on this line of reasoning, we hypothesized that monolinguals and older adults would be especially penalized in dual-task conditions when the concurrent tasks consist of words that are highly semantically similar, relative to bilinguals and younger adults.

To summarize these various strands of the argument, the present study was a memory experiment in which participants listened to a list of words drawn from a single semantic category and then recalled the words orally in any order. The list was encoded and retrieved either alone (FA conditions) or simultaneously with an interfering task (DA conditions) consisting of visually presented words from the same or a different semantic category as the memory list; participants made size judgments manually to the visual words. One point of interest was whether semantic relatedness between the memory and distracting task would increase the memory decrement associated with DA at either encoding or retrieval; these data will further specify the nature of encoding and retrieval processes. Finally, the participants were younger and older adults who were bilingual or monolingual. On the basis of previous findings, we predicted that younger adults and bilinguals would be better able to resist the interfering effects of the secondary task, especially when the two tasks used semantically related materials.

#### Method

In each of five different conditions, participants were asked to learn an auditorily presented list of semantically related words, and were then given a free recall task for the words. In four different DA conditions, at either encoding or retrieval, participants performed a distracting task requiring size decisions on words that were either semantically related or unrelated to those in the memory task. Participants also performed a baseline full attention (FA) condition, in which no distracting task was present at either encoding or retrieval.

#### Participants

There were 104 participants in the study, drawn from two language groups and two age groups. Fifty-two young undergraduate students, ranging in age from 17 to 27 years (mean = 20.5 years; 36 female), participated in the experiment for course credit or token monetary remuneration. In addition, 52 older adults, ranging in age from 60 to 79 (mean = 70.1 years; 36 female), were recruited through flyers and posters in the community; they participated for monetary remuneration. In each group, half of the participants were monolingual English speakers, and the other half were bilingual speakers.

The monolingual participants were not fluent in any other language (based on self-report; see Language Questionnaire in Appendix) although they may have taken language courses in school. Research with bilingual adults (Kroll & Stewart, 1994) and bilingual children (Bialystok, 1988) has found that the cognitive and

linguistic effects of bilingualism are more pronounced in those bilinguals who are relatively balanced in their proficiency and usage of each language; thus the criterion of balanced bilingualism was used for selection of the sample in the present study. Based on data from a language background questionnaire, all of the bilingual participants reported using a language other than English on a daily basis to communicate with others, and were proficient in understanding, speaking, reading, writing, and communicating with that other language. In the majority of cases, the participants spoke a language other than English at home and used English in the community, at work, and at school. This arrangement leads to the balanced daily use of both languages. For participants in the younger group, the criterion was that the individual has been using two languages regularly since starting school, at about 6 years old; for participants in the older group, the criterion was that the individual has been using both languages regularly since early adolescence, at about 12 years old. The non-English language of the bilinguals included a wide range of languages, such as Cantonese, Italian, Portuguese, Hindi, French, Spanish, Greek, Hebrew, and Arabic, with no one language being overrepresented.

#### Tasks

*Language background questionnaire.* This questionnaire was filled out by the experimenter while interviewing the participant on language use and fluency in the two languages for the bilingual participants. Responses indicate the extent to which each language is used daily, and the degree to which the participant is functionally bilingual (see Appendix).

*Peabody Picture Vocabulary Test – Revised (PPVT-III; Dunn & Dunn, 1997).* This is a standardized test of receptive vocabulary, consisting of a series of plates, each containing four pictures. The experimenter names one of the pictures, and the participant indicates which picture illustrates that word. Trials become increasingly difficult, and testing continues until the participant makes six errors in eight consecutive trials. The test was administered in English to all participants in our study.

*Digit Span.* This test provides an assessment of working memory capacity. It is composed of two parts and is a subtest of the Wechsler Memory Scale, revised (Wechsler, 1987). The first part requires participants to repeat sequences of three to nine digits, and the second requires them to repeat sequences of two to eight digits, in reverse order of that recited by the experimenter. Trials continue until the participant makes errors during repetition of both sequences of a given

length. The total number of successfully repeated trials is the participant's score.

*Cattell Culture Fair Intelligence Test* (Cattell & Cattell, 1960). This test is a nonverbal assessment of general intelligence. The raw scores are converted into IQ scores by a set of tables based on age.

*Experimental task.* Five categories were chosen from a list of category norms for verbal items (Battig & Montague, 1969). These were animals, fruits, musical instruments, tools, kitchen items. For each category, 40 words were selected, omitting the top six exemplars from each category. Each list was subsequently divided into two lists of 20 words each, (List A and List B), balanced for word length (mean = 6.19,  $SD$  = 0.62 letters), category strength (mean frequency of exemplar = 74.8,  $SD$  = 15.2), and word frequency (mean = 36.09 occurrences per million,  $SD$  = 14.17; Thorndike & Lorge, 1944). List A words were used in the Memory Task, and List B in the Distracting Task. Another two lists of 10 words each were created; these consisted of abstract words (e.g., peace, envy) to be used as study lists during the practice session. Each word from the Memory Task lists was spoken by a research assistant, and recorded into a .wav file using SoundDesigner II software (Palo Alto, California). Words for the distracting task were presented visually in black letters on a white background.

### Procedure

Participants were tested one at a time, using E-Prime software for stimulus presentation and collection of accuracy and reaction time (RT) data. After signing a consent form, each participant completed the Language Background questionnaire. Next, the PPVT-R was administered, followed by the Digit Span task. They were then told that the experiment had five conditions: Full attention at both encoding and retrieval, DA at encoding, related words, DA encoding-unrelated, DA retrieval-related, DA retrieval-unrelated. Participants were also told that a set of puzzles (nonverbal Cattell Test) would be given following each section, as a break from the verbal memory task. The experiment procedure was then explained, and a practice session administered. The practice phase allowed participants to practice a DA at encoding condition and a DA at retrieval condition. The study took approximately one hour to complete.

During the study phase in each of the five experimental conditions and in the two practice conditions, participants heard words presented from the computer speakers at a rate of one word every three seconds. Twenty-word lists were used for the experimental con-

ditions and 10-word lists for the practice conditions. Words in each of the experimental lists were from a single category (see above). Participants were instructed to remember the words for a later memory test but were not explicitly informed that the words in the list belonged to a single category. Following the study phase, participants counted backward by 3s for 30 s from a number shown on the computer monitor, to prevent recency effects on the subsequent free recall test. They were then prompted to repeat out loud all words that they could remember from the study list. They were given 60 seconds for this retrieval phase.

In the FA condition, participants listened to the study list and then performed free recall without any distracting (concurrent) task. In the DA encoding conditions, participants heard the study list while simultaneously performing the visually presented distracting task, and in the DA retrieval conditions they verbally recalled words while performing the distracting task. In each DA condition, participants were told to divide their efforts equally across the two tasks. The distracting task in these DA conditions involved presentation of a word (either "monitor," "keyboard," "CPU," or "mouse") in the upper right corner of the computer screen; the word represented the reference object for the size decision distracting task and remained on the screen throughout the duration of the distracting task. Distracting task trials involved the presentation of List B words, one at a time in the centre of the computer screen, for 2,500 ms, with a 500 ms interstimulus interval. Participants were told to visualize the object that the word represented, and to compare the size of that object to the size of the object in the upper corner of the monitor, and then to press the appropriate response key on the keyboard to indicate whether the object was larger or smaller than the reference object. The category relationship between the list of words in the memory and distracting tasks was manipulated in the study such that distracting task words were either from the same (related) or different (unrelated) category as the memory task words.

There were two DA at encoding conditions. In the DA encoding-related condition, the distracting task used List B words from the *same category as the memory task words*. In the DA encoding-unrelated condition, the words for the distracting task were List B words from a category *different* from that in the memory task. Participants were told that while they were listening to, and trying to memorize, the auditorily presented words, they would also have to make size judgments for the visually presented distracting task words, with an equal emphasis on both tasks. After the study phase, and counting backwards, participants were given 60 seconds to recall words from the memory task. In this case, retrieval was under FA conditions.

TABLE 1  
Mean Background Measures (and Standard Errors) by Age and Language Group

| Measure              | Younger     |             | Older       |             |
|----------------------|-------------|-------------|-------------|-------------|
|                      | Monolingual | Bilingual   | Monolingual | Bilingual   |
| Age (in years)       | 21.2 (0.5)  | 19.8 (0.3)  | 70.5 (0.9)  | 69.7 (0.8)  |
| Education (in years) | 14.9 (0.4)  | 13.9 (0.3)  | 15.5 (0.5)  | 16.3 (0.5)  |
| PPVT – III raw       | 154.7 (2.4) | 150.8 (2.4) | 195.4 (1.7) | 184.0 (2.9) |
| Cattell              | 114.5 (2.9) | 110.3 (3.0) | 113.3 (2.4) | 105.1 (3.0) |
| Digit Span           | 16.8 (1.5)  | 16.7 (1.5)  | 15.8 (1.2)  | 16.7 (0.9)  |

Note. PPVT-III = Peabody Picture Vocabulary Test-Third Edition; Cattell = Cattell Culture Fair Intelligence Test

TABLE 2  
Mean Number of Words Recalled (and Standard Errors) by Age and Language Group for Each Memory Condition

| Condition and Language Group | Younger    | Older     |
|------------------------------|------------|-----------|
| Full Attention               |            |           |
| Monolingual                  | 10.7 (0.5) | 9.2 (0.5) |
| Bilingual                    | 10.0 (0.5) | 7.9 (0.5) |
| DA encoding – related        |            |           |
| Monolingual                  | 5.9 (0.4)  | 4.4 (0.3) |
| Bilingual                    | 5.6 (0.5)  | 4.1 (0.3) |
| DA encoding – unrelated      |            |           |
| Monolingual                  | 7.5 (0.5)  | 5.8 (0.5) |
| Bilingual                    | 6.6 (0.4)  | 4.8 (0.4) |
| DA retrieval – related       |            |           |
| Monolingual                  | 8.5 (0.6)  | 6.3 (0.4) |
| Bilingual                    | 6.8 (0.6)  | 6.2 (0.4) |
| DA retrieval – unrelated     |            |           |
| Monolingual                  | 8.4 (0.5)  | 6.4 (0.5) |
| Bilingual                    | 7.9 (0.4)  | 5.8 (0.5) |

Note. DA = divided attention

There were also two DA at retrieval conditions. In the DA retrieval-related condition, participants studied words under full attention, but during retrieval performed the distracting task in which the List B words were from the same category as the memory task words. In the DA retrieval-unrelated condition, the words for the distracting task were List B words from a category different than that in the memory task. The order of presentation of the five experimental conditions was counterbalanced across participants.

### Results

The background measures of age, education, digits span, PPVT-III, and Cattell scores are shown in Table 1. A two-way analysis of variance (ANOVA) on education level showed no differences across language group ( $F_s < 1$ ), but the older group had more years of education than the young group,  $F(1, 100) = 11.44, p < .01$ . A similar analysis on digit span scores showed no differences for either language or age groups (both  $F_s < 1$ ). The ANOVA on Cattell scores showed higher scores for monolingual than bilingual participants,  $F(1, 100) = 5.28, p < .05$ , though no difference in scores across age

groups,  $F(1, 100) = 1.42, p > .05$ . The correlation of Cattell scores with total recall was significant ( $r = .37, p < .01$ , 2-tailed). Cattell scores were not correlated with total recall scores within the group of older monolinguals ( $r = .02, p = .91$ ), nor with younger or older bilinguals ( $r = .36, p = .07$  and  $r = .17, p > .05$ , respectively). Younger monolinguals, however, showed a significant positive correlation with total recall ( $r = .76, p < .01$ ). The ANOVA on PPVT raw scores showed higher scores in the monolingual,  $F(1, 100) = 10.19$ , and older participant groups,  $F(1, 100) = 237.52, p_s < .01$ . PPVT scores were correlated with total recall scores ( $r = -.24, p < .01$ , 1-tailed). However, these scores were not correlated with total recall within the group of younger ( $r = .30, p = .13$ ) or older monolinguals ( $r = .27, p = .19$ ), nor with younger ( $r = .17, p = .42$ ) or older ( $r = .21, p = .30$ ) bilinguals.

### Memory Task

*Number of words recalled.* The mean number of words recalled by age and language group are shown in Table 2 for each condition. We conducted a 4-way ANOVA on the DA conditions. The analysis was a mixed 2 (Age group; young, old)  $\times$  2 (Language group; monolingual, bilingual)  $\times$  2 (Phase of attention manipulation; at encoding, at retrieval)  $\times$  2 (Relatedness; related, unrelated) ANOVA with the first two factors being between- and the others within-subject manipulations, using number of words recalled as the dependent measure. There was a main effect of Phase,  $F(1, 100) = 59.81, p < .001$ , a main effect of Relatedness,  $F(1, 100) = 15.31, p < .001$ , and a Phase  $\times$  Relatedness interaction,  $F(1, 100) = 6.87, p < .01$ , showing that fewer words were recalled in the DA at encoding than retrieval conditions, and that performance was impaired more by related than by unrelated words in the distracting task. Planned contrasts showed that the negative effect of having related words in the distracting task was significant during DA at encoding,  $F(1, 100) = 266.83, p < .001$ , but not during DA at retrieval,  $F(1, 100) = .51, p = .48$ . There was also a main effect of Age,  $F(1, 100) = 26.03, p < .001$ , with older adults recalling fewer words than younger adults, and a main

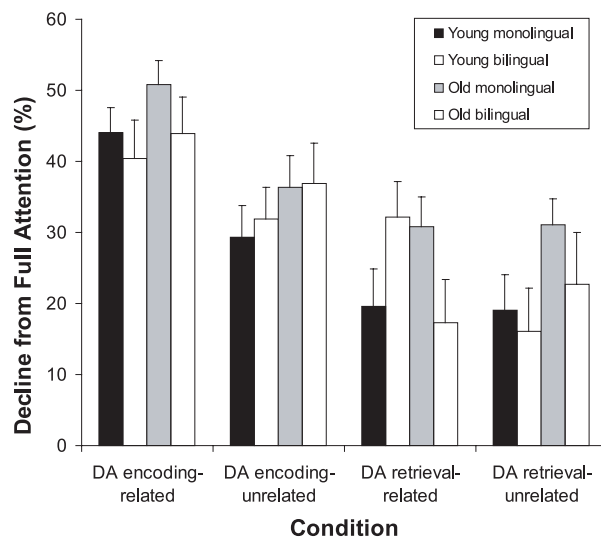


Figure 1. Mean percentage decline in recall from full attention in each age and language group for each condition. Error bars represent standard errors. DA = divided attention.

effect of Language,  $F(1, 100) = 4.37, p < .05$ , with bilinguals recalling fewer words than monolinguals. There were no other significant main effects or interactions.

#### *Percentage decline in memory under DA conditions.*

In the following analyses, we considered the percentage decline in words recalled from baseline (FA) in each of the DA conditions. This was calculated by subtracting the number of words recalled in each DA condition from its corresponding FA condition, dividing by the number of words recalled under FA, and then multiplying this value by 100 to get a percentage decline score. In this way we could examine directly the interference effects from DA, relative to each participant's own FA level of recall (see Figure 1).

We conducted a further mixed 2 (Age)  $\times$  2 (Language)  $\times$  2 (Phase of attention)  $\times$  2 (Relatedness) ANOVA with the first two factors being between- and the others within-subject manipulations, using percentage decline in recall as the dependent measure. The pattern of significant results was the same as above, except for two key differences. Unlike the results using number of words as the dependent variable, there was no effect of age,  $F(1, 100) = 1.77, p = .19$ , or language,  $F < 1$ , on the magnitude of memory interference, nor did these between-subject variables interact with any other variable. These results indicate that while age and language group lead to poorer memory recall, these factors do not amplify susceptibility to memory interference. There were no other significant main effects or interactions.

#### *Hierarchical regression and covariance analyses.*

Because our study includes multiple variables that can each contribute to memory performance, we sought to determine the proportion of variance in overall recall score that can be accounted for by each of our predictors. We conducted a hierarchical regression analysis in which we determined the  $R^2$  value for each predictor, indicating the unique percentage of variance that can be accounted for by a given variable once variance common with the other predictors is partialled out. The regression was conducted with age, PPVT raw score, and Cattell standardized score as predictors. The linear combination of these three measures was significantly related to total recall scores,  $R^2 = .32$ , adjusted  $R^2 = .30$ ,  $F(3, 100) = 15.63, p < .001$ . Of the three predictors, age was the most strongly related to total recall, with a part correlation of  $-.33 (p < .001)$ , indicating that 11% of the variance can be accounted for by age alone. Cattell score and PPVT were also uniquely correlated with total recall with part correlations of  $.27 (p < .01)$  and  $.13 (p = .10)$  respectively, accounting for 7.6% and 2% of the variance each.

In order to examine whether the main effects of age and language on total number of words recalled were significant after controlling for PPVT and Cattell scores, we conducted an analysis of covariance, using the total number of words recalled across all conditions as the dependent variable. The main effect of age group remained significant,  $F(1, 98) = 14.95, p < .001$ , with older adults recalling fewer words than younger adults, but the main effect of language group, and its interaction with age group, was nonsignificant,  $F(1, 98) = 0.91$ , and  $F(1, 98) = 1.08, ps > .05$ , respectively.

The difference in Cattell scores for the monolinguals and bilinguals indicates that the groups may not be comparable in their level of cognitive functioning. Therefore, we examined the distributions of Cattell scores and found that it was normally distributed for the monolingual group, but bimodal for the bilinguals; there were six participants in the bilingual group (three in the younger and three in the older age group) who obtained a score less than 90, which is very low. By omitting these individuals, all participants in both groups had scores between 90 to 146, and the mean Cattell score was comparable across language groups,  $F(1, 94) = 1.57, p = .21$ . In contrast, the mean difference in PPVT scores remained after excluding these six participants,  $F(1, 94) = 6.66, p < .05$ , with monolinguals achieving higher scores than bilinguals.

We then conducted a repeated measures 4-way ANOVA, excluding these six bilingual participants with low Cattell scores, using number of words recalled as the dependent variable. The analysis was a mixed 2 (Age group; young, old)  $\times$  2 (Language group; mono-

TABLE 3

Mean Accuracy and Reaction Time on the Size Judgments Distracting Task (and Standard Errors) by Age and Language Group, During Each Dual-Task Condition

| Condition and Language group | Younger      |           | Older        |           |
|------------------------------|--------------|-----------|--------------|-----------|
|                              | Accuracy (%) | RT (ms)   | Accuracy (%) | RT (ms)   |
| DA encoding – related        |              |           |              |           |
| Monolingual                  | 80 (.04)     | 1524 (47) | 71 (.03)     | 1488 (49) |
| Bilingual                    | 75 (.03)     | 1601 (45) | 66 (.04)     | 1507 (57) |
| DA encoding – unrelated      |              |           |              |           |
| Monolingual                  | 74 (.04)     | 1548 (44) | 65 (.05)     | 1531 (69) |
| Bilingual                    | 67 (.04)     | 1600 (55) | 64 (.03)     | 1546 (41) |
| DA retrieval – related       |              |           |              |           |
| Monolingual                  | 56 (.03)     | 1642 (50) | 51 (.04)     | 1597 (49) |
| Bilingual                    | 56 (.04)     | 1613 (38) | 49 (.03)     | 1682 (53) |
| DA retrieval – unrelated     |              |           |              |           |
| Monolingual                  | 68 (.03)     | 1516 (54) | 50 (.03)     | 1569 (40) |
| Bilingual                    | 62 (.04)     | 1511 (39) | 54 (.04)     | 1612 (47) |

Note. DA = divided attention; RT = reaction time.

lingual, bilingual)  $\times$  2 (Phase of attention manipulation; at encoding, at retrieval)  $\times$  2 (Relatedness; related, unrelated) ANOVA with the first two factors being between- and the others within-subject manipulations. As in the original analysis (which included all participants), there was a main effect of Phase,  $F(1, 94) = 54.52$ ,  $p < .001$ , a main effect of Relatedness,  $F(1, 94) = 13.29$ ,  $p < .001$ , and a Phase  $\times$  Relatedness interaction,  $F(1, 94) = 6.10$ ,  $p < .05$ , showing that fewer words were recalled in the DA at encoding than retrieval conditions, and that performance was more impaired by related than by unrelated words in the distracting task. Planned contrasts again showed that the negative effect of having related words in the distracting task was significant during DA at encoding,  $F(1, 94) = 18.83$ ,  $p < .001$ , but not during DA at retrieval,  $F(1, 94) = .47$ ,  $p = .49$ . The main effect of age remained significant,  $F(1, 94) = 29.76$ ,  $p < .001$ , with older adults recalling fewer words than younger adults, and the main effect of language group was nearly significant,  $F(1, 94) = 3.69$ ,  $p = .06$ , with bilinguals recalling fewer words than monolinguals. There were no other significant main effects or interactions. The results were similar when applied to the percentage decline data. Because the effect of Language group was close to being significant, we conducted a follow-up multivariate ANOVA to examine memory performance in monolinguals compared to bilinguals in the five conditions. Results showed that the bilinguals recalled fewer words than monolinguals in the full attention,  $F(1, 94) = 3.93$ ,  $p = .05$ , and in the DA encoding unrelated condition,  $F(1, 94) = 3.94$ ,  $p = .05$ , but that the two groups performed the same in the other conditions.

### Distracting Task

The mean accuracy rate and RT to correct responses on the distracting task are shown in Table 3 for each condition. We conducted a mixed 2 (Age)  $\times$  2 (Language)  $\times$  2 (Phase)  $\times$  2 (Relatedness) ANOVA with the first two factors being between- and the others within-subject manipulations, using accuracy rate as the dependent measure. There was a main effect of Phase,  $F(1, 100) = 106.16$ ,  $p < .001$ , such that distracting task performance was worse during DA at retrieval than during DA at encoding (see Table 3), and a Phase  $\times$  Relatedness interaction,  $F(1, 100) = 14.07$ ,  $p < .001$ . Interestingly, having related rather than unrelated words in the distracting and memory task led to lower accuracy during DA at retrieval, but the reverse was true for DA at encoding. There was also a main effect of Age,  $F(1, 100) = 11.02$ ,  $p < .001$ , with older participants showing poorer accuracy than young in all DA conditions. There were no other significant main effects or interactions.

We also conducted a mixed 2 (Age)  $\times$  2 (Language)  $\times$  2 (Phase of attention)  $\times$  2 (Relatedness) ANOVA on RT to correct responses. There was a main effect of Phase,  $F(1, 100) = 4.05$ ,  $p < .05$ , with slower RTs in the DA retrieval than DA encoding conditions, a trend for a Phase  $\times$  Age interaction, with older adults showing slower RTs during the DA retrieval conditions, but faster RTs than young in the DA encoding conditions,  $F(1, 100) = 3.76$ ,  $p < .06$ , and a Phase  $\times$  Relatedness interaction,  $F(1, 100) = 7.12$ ,  $p < .01$ , such that relatedness increased RTs more under DA at retrieval; in fact, relatedness served to decrease RTs slightly, under DA at encoding. There were no other significant main effects or interactions.

Finally, we considered the correlations between

memory and distracting task accuracy performance under each DA condition as an indicator of trade-offs between the dual-tasks. There were no significant correlations between memory interference and performance on the distracting task in any DA condition in the monolingual group (all  $ps > .05$ ), in the bilingual group (all  $ps > .05$ ), and in the older adult group (all  $ps > .05$ ). In younger adults, all correlations were non-significant except in the DA at retrieval-related condition; here there was a negative correlation ( $r = -.32$ ,  $p = .02$ ) such that larger memory interference scores were associated with poorer distracting task performance. These results argue against the possibility that participants are favouring one task in order to better perform the other.

### Discussion

The major purpose of the study was to explore the effects of aging and bilingualism on memory performance in a dual-task situation. Previous work had shown that bilinguals have better attentional control in conditions involving conflict, so our assumption was that they would be better able to resist the effects of a concurrent distracting task. We also predicted that older adults would show greater DA costs than their younger counterparts in secondary task performance in the retrieval phase (Anderson et al., 1998; Craik & McDowd, 1987), and that bilingualism would attenuate this age-related decrement. Finally, the distracting task used in the study was either related or unrelated to the material in the memory task; we predicted greater interfering effects from related materials, and that bilingual participants would be better able to resist this increased interference. Some of these predictions were upheld but several were not. We discuss them in turn, and note the implications for a fuller understanding of the effects of aging, bilingualism, and semantic relatedness on the ability to divide attention during the encoding or retrieval phase of a memory task.

#### *Effects of Aging and Bilingualism*

Considering first the effects of bilingualism and aging on memory performance (Table 2), analysis of the DA conditions revealed significant effects of both age (young > old) and language group (monolinguals > bilinguals), but no Age x Language interaction, and no interactions with other variables. The superior recall by younger participants was expected, but the poorer performance of bilinguals was at first surprising. However, studies have shown that bilinguals perform poorly on tasks involving lexical access (Gollan, Montoya, & Werner, 2002; Ransdell & Fischler, 1989; Rosselli et al., 2000), and based on the current study, it appears that there may also be a bilingual *disadvantage* for memory

retrieval – in the case of verbal materials at least. In support of this claim, a bilingual disadvantage was found in the full attention condition (Table 2), and the effect was somewhat greater in the older group. The results of the covariance analysis showed that when PPVT (vocabulary) and Cattell (nonverbal assessment of IQ) scores are partialled out, the negative effect of bilingualism disappears. It may be that bilinguals have smaller vocabularies in any one of their languages than do native speakers of that language, and that it is this smaller vocabulary that is associated with poorer lexical access, including memory retrieval. In support of this, when we equated the Language groups on Cattell scores, there was still a difference between language groups on PPVT scores, and along with this, a strong trend for bilinguals to recall fewer words in the experimental conditions compared to monolinguals, and a significant difference between the groups under full attention.

When the percentage decline from full attention is considered (Figure 1), no effects of aging or bilingualism were found. It thus appears that while both variables affect recall output, neither variable affects susceptibility to memory interference caused by a distracting task. The finding of similar drops in memory performance as a result of a DA task between younger and older adults confirms previous results reported by Anderson et al. (1998), Naveh-Benjamin, Craik, Guez and Dori (2005), and Nyberg et al. (1997), but the failure to find a bilingual advantage in resisting the effects of interference goes against our prediction. It is noteworthy that bilinguals recalled fewer words than monolinguals in the simplest condition (under FA), but were no worse than monolinguals when task demands increased. That is, in three of the four DA conditions there was no significant difference in number of words recalled across language groups. Thus being bilingual may have imparted some advantage in resisting the effects of DA; otherwise, they should have shown greater decrements in recall in all of the more difficult DA conditions. Clearly, further work is required to specify those tasks in which bilingualism confers an advantage, but an interim conclusion is that bilingual participants show an advantage in tasks involving executive control, and a disadvantage in tasks involving lexical access, including verbal memory retrieval; further, based on the present results, the latter effect may be attributable to the smaller vocabulary scores associated with bilingualism.

Performance on the secondary distracting task was not affected by the language variable, but there was a large effect of aging on accuracy, with older adults classifying fewer words correctly in all conditions (Table 3). On the RT measure, there was a marginally

significant interaction ( $p < .06$ ) between age and memory phase, with older participants being generally slower than their younger counterparts when classifying words during retrieval (in line with the results of Anderson et al., 1998) but slightly faster than younger participants during encoding. This latter result may reflect the older participants' underestimation of the amount of attention that should be given to memory encoding in order to support good levels of subsequent recall.

### *Effects of Relatedness*

Our prediction that the related classification task would interfere with memory performance more than the unrelated task was confirmed (Table 2), but unexpectedly this effect interacted with phase of the memory task, being greater at encoding than at retrieval. The finding that encoding is more susceptible to attentional manipulations than retrieval is in line with previous work, which has shown consistently large effects of DA at encoding on subsequent memory performance (Anderson et al., 1998; Baddeley et al., 1984; Craik et al., 1996; Fernandes & Moscovitch, 2000; Murdock, 1965; Naveh-Benjamin et al., 1998), regardless of the type of distracting task concurrently performed.

What is novel about our current findings is that the magnitude of memory interference was selectively greater depending on the semantic association between words in the memory and concurrent task. That interference was larger in the DA encoding-related than DA encoding-unrelated condition suggests that competition for general attentional resources is not an adequate account for why DA at encoding produces such large memory interference effects. Instead, our results suggest that encoding is sensitive to the nature of the distracting task, and that competition for *specific resources* can also occur. An alternative possibility is that when the unrelated distracting task is performed at encoding, there is no confusion about which words to recall in the later retrieval phase, since the words come from different categories. All words come from the same category in the related case, however, which may decrease the distinctiveness of words during encoding, thus hampering later retrieval.

We also note that the effect of semantic relatedness of words in the memory and distracting tasks was smaller, and nonsignificant, at retrieval. This finding lends support to the hypothesis put forth by Fernandes and Moscovitch (2002), suggesting that the primary locus of the material-specific memory interference effect from DA at retrieval is at the level of phonology rather than at the level of competition for semantic representations. If it were semantics, then the semantic relatedness factor in the present study should have

modulated the magnitude of memory interference at retrieval (as it did at encoding), but it did not. The pattern of results was similar in the percent decline scores, with the related classification task leading to more interference than the unrelated task, but with that effect seen during encoding only (Figure 1). As suggested previously, the interference effect at encoding may reflect specific attentional mechanisms or may reflect a type of "cue-overload" effect during the subsequent retrieval phase.

Relatedness also affected performance on the secondary classification task. In both the accuracy measure and the RT measure, relatedness interacted with phase of the memory task such that during encoding, performance on the classification task was better (higher accuracy, lower RT) in the related condition whereas during retrieval, performance on the secondary task was better in the unrelated condition. This retrieval effect on secondary task performance suggests that retrieval is sensitive to semantic relatedness manipulations, but that it impairs secondary and not memory task performance. Fernandes and Moscovitch (2002) suggested that retrieval success is more sensitive to phonological than semantic manipulations in the secondary task material. Because semantic relatedness did not influence the magnitude of memory interference during retrieval, our results are in line with their suggestion. However, the findings of greater secondary task costs suggests that manipulations of semantic relatedness may affect postretrieval monitoring, or checking processes, as indexed by the increase in secondary task costs.

The other aspect of the Phase  $\times$  Relatedness interaction, on distracting task performance, namely, that classification performance is better for related items during encoding, is less easy to explain. One possibility is that classification within a semantic category may be easier when the words to be encoded for memory are in that same category, for the reason that fewer switches of set are required. On the other hand, it would seem that this explanation should also apply to retrieval. In the RT data, the interaction is driven largely by the retrieval difference (82 ms in favour of unrelated) as opposed to the encoding difference (26 ms in favour of related). So semantic interference at retrieval may be the major contributing factor to the interaction.

### *Encoding and Retrieval Under Dual-Task Conditions*

The present results generally confirmed previous findings of an asymmetry in the effects of a secondary task on encoding and retrieval. That is, the distracting task reduced performance more when it was performed at encoding than at retrieval (see also Baddeley et al., 1984; Craik et al., 1996; Fernandes & Moscovitch,

2000). However, the results also showed that the greater effect of DA at encoding was further amplified when the distracting task was related to the memory task. The present results also confirmed that performance of the secondary task is more impaired when it is carried out during retrieval as opposed to encoding, and further showed that this effect too was amplified by relatedness. Thus relatedness between the concurrent tasks increases both the negative effects of DA at encoding on memory performance, and that of DA at retrieval on secondary task performance. Yet our results also showed that there is no simple trade-off between memory and distracting task performance.

What gives rise to these differences between encoding and retrieval? One plausible factor is that retrieval during free recall is under the participant's control; he or she can choose when to concentrate on retrieval and when to attend more closely to the secondary task. On the other hand, this is much less true of encoding where stimulus presentation is under experimental control. However, this account was explicitly investigated and rejected by Craik, Naveh-Benjamin, Ishaik, and Anderson (2000). They presented paired-associate word lists for learning and recall either at a fixed rate or at a rate controlled by the participant, and found that a secondary task had a greater deleterious effect at encoding than at retrieval under all conditions of experimenter and participant control.

A second possibility is that success and failure are more obvious to participants at retrieval than at encoding, so participants may simply choose to devote more attention to the memory task at retrieval than at encoding. The finding that performance on the secondary task is poorer when combined with retrieval supports this interpretation. But if retrieval performance is maintained at a high level in dual-task conditions by virtue of more attention being devoted to it, then an increase in secondary task difficulty should hurt performance in the DA-retrieval condition more than in the DA-encoding condition. In fact the opposite is true; in the present study, an increase in relatedness affected encoding more than retrieval, and in a previous study a direct manipulation of the relative amounts of attention paid to the memory task and the distracting task showed large effects during DA at encoding and little or no effect during DA at retrieval (Craik et al., 1996).

Another possible explanation for why manipulations of attention at encoding are more detrimental than at retrieval may lie in the processes critical for establishment of a memory trace. That is, perceptual processing is also severely impaired in the absence of attention, as noted in cases of attentional blindness (Mack, Tang, Tuma, Kahn, & Rock, 1992; Rock, Linnett, Grant, & Mack, 1992). Thus an inefficiency or inability to per-

form perceptual analysis likely also impacts on one's encoding capacity. This account of DA effects at encoding, however, cannot be the only reason for poorer memory following manipulations of attention at encoding, because again, it predicts no difference in memory interference depending on semantic relatedness of the distracting tasks. Our results are contrary to this hypothesis, and suggest that encoding is particularly impaired when there is competition for semantic processing resources. Perhaps having similar material in the distracting task during encoding limits the depth to which that item can be processed, leading to poorer memory.

On the basis of our evidence, our conclusion is that the processes of encoding and retrieval differ substantially in a number of respects, casting doubt on earlier views that emphasized the similarity or even equivalence of the two sets of processes (e.g., Craik, 1983; Kolers, 1973; Morris et al., 1977). Encoding operations clearly depend on the amount of attention available; they are also affected by the similarity of distracting-task processing (current study). Retrieval operations are less affected by a simple withdrawal of attentional resources (Craik et al., 1996), but are strongly affected by the phonemic similarity of concurrent processing (Fernandes & Moscovitch, 2000, 2002). The present study also confirmed that aging is associated with poorer memory performance but does not affect the loss of memory caused by a concurrent task. Finally, bilingualism is associated with poorer performance on verbal memory tasks, in contrast to the processing advantage shown by bilinguals in other studies that document enhanced executive function in this group.

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Appendix

## Language Background Questionnaire

Participants answer each of the following questions posed by the experimenter.

## Part 1.

1. What is your mother's language?
2. What is your father's language?
3. Your place of birth:
4. Your date of birth:
5. Do you consider yourself mono/multilingual?
6. List all the languages you speak.

For each language listed, these questions are asked:

- a) As of what age did you speak this language?
- b) From whom did you learn the language?
- c) Do you use this language on a regular basis to communicate with others?

For each language, rate on a scale of 1-10 how well you

- a) understand
- b) speak
- c) read/write

## Part 2. Hypothetical situations

1. Suppose you are stranded in a rural area of a country in which any one of the languages (except English) you indicated above was the only one spoken. Now suppose that you require immediate medical attention, but you are also allergic to penicillin and other antibiotics. Would you be able to communicate this to one of the locals and receive the medical attention you require?

Yes                      No

2. Suppose you have just spent the last three months in a country where the spoken languages are English and one of the languages you indicated above. If the local newspapers were available in both English and your other language, which version would you read?

English                  Other language