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THE EFFECTS OF ATTENTION SWITCHING ON ENCODING AND RETRIEVAL OF WORDS IN YOUNGER AND OLDER ADULTS

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Two experiments examined the interaction between aging, attention switching, encoding process, and recognition memory using different versions of a cued attention switching paradigm. In Experiment 1, 30 younger and 35 older adults encoded words based on font color, meaning, or by explicit learning with a color response during performance of a choice–reaction time (RT) task. Attention switches were cued by means of stimulus location, and occurred on average every seven trials. In Experiment 2, attention switching was precued from a central fixation point and the number of critical switch trials was increased, occurring on average every four trials. Memory was assessed in both experiments by means of a forced-choice recognition task. Results indicated that, relative to color encoding, older adults benefited more than younger adults from semantic encoding, but less from explicit learning instructions.

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Attention switching disrupted encoding task performance of older adults more than that of younger adults, but recognition memory was generally unaffected. Results are discussed in light of theoretical models of aging memory that posit a role for executive control processing.

In everyday situations we are faced with a highly complex and ever-changing environment in which we must frequently switch among tasks, behavioral goals and intentions, sources of information, chains of thought, and actions. Amidst this frequent switching of attention we must not only retrieve from memory information that allows us to carry out our goals, but also encode and store new information about current tasks and situations for future use. To form an intention to perform a particular task is to adopt a task set (or mental set). Both the adoption of task set and switching from one task set to another involves executive control (Rogers & Monsell, 1995; Shallice, 1994).

Executive control involves the ability to manage one's thoughts, memories and actions in accordance with task-relevant goals (Anderson & Craik, 2000). In addition to attention switching, component processes include sustained attention (Posner & Peterson, 1990), inhibition (Shimamura, 1995), working memory (Baddeley, 1986), and goal maintenance (Duncan, 1995), functions generally hypothesized to be localized within the frontal lobes of the brain (e.g., Norman & Shallice, 1986; Shallice, 1988, 2002). Decrements in such control functions in older adults are well established, and the frontal lobe hypothesis of aging is often used to account for these decrements (see West, 1996; Craik & Grady, 2002; for reviews; see Rabbit, Lowe, & Shilling, 2001 for a critique).

In the current study, we were interested in examining the relation between executive control and aging memory by asking the following question: does the requirement to switch attention during encoding have an effect on the acquisition of new memories in younger and older adults?

Memory and Aging

Craik (1986) argued that, due to limitations in processing resources, the ability to self-initiate optimal processing functions at both encoding and retrieval is particularly problematic for older adults. As a result, older adults do not spontaneously engage in cognitively demanding processes such as deep, semantic encoding and thus retain less. According to Craik, however, these memory deficits may be largely overcome by the provision of external support during a memory task (for comprehensive reviews of aging memory, see Anderson & Craik, 2000;

Craik & Jennings, 1992; Kausler, 1994; Light, 1991; Smith, 1996). For example, Craik and Byrd (1982) and Craik and Simon (1980) reported a series of experiments in which age-related decrements were greatest in conditions that demanded self-initiated learning, but were minimised or eliminated when deep encoding was encouraged by semantic orienting tasks.

Anderson and Craik (2000) proposed that the age-related neurological alterations occurring in the frontal lobes with increasing age mediate two general cognitive changes: a reduction in the amount of attentional resources available for complex cognitive tasks (Craik, 1983) and a reduction in the processing speed of elemental cognitive processes (e.g., Salthouse, 1996). According to Anderson and Craik, age-related reductions in cognitive resources and age-related cognitive slowing act to reduce overall cognitive control.

The dual-task paradigm offers a useful methodology for examining the relation between aging and cognitive control in complex task environments. For example, Anderson, Craik, and Naveh-Benjamin (1998) asked younger and older adults to engage in free recall, cued recall, or recognition while performing a secondary continuous reaction time (RT) task during either encoding or retrieval. Dividing attention at encoding disrupted memory performance equally for the two age groups, whereas dividing attention at retrieval had little or no effect on memory performance for either age group. However, secondary task RTs were slowed to a greater extent for the older adults than for the younger adults, especially at retrieval. Furthermore, age-related differences in RT costs at retrieval were largest in free recall, smaller in cued recall, and smallest in recognition, replicating the results of Craik, Naveh-Benjamin, and Anderson (1996). The authors concluded that though both older and younger adults' memory is equally disrupted by a secondary task at either encoding or retrieval, such mnemonic processes are more effortful for older adults, evidenced by greater secondary task performance decrements. The results therefore provide evidence for an age-related increase in the attentional demands of encoding and retrieval (see Anderson & Craik, 2000, for a discussion).

Attention Switching and Aging

The process of switching between mental sets has been extensively investigated using the task-switching paradigm, in which participants must constantly switch between two RT tasks. The effects of a task switch are observed in an increased RT for the first trial after a switch of task. This time cost is generally interpreted as the time required to complete the control processes involved in switching from one task to the other (from one mental set to another). A second, more general effect of task switching is known as 'mixing cost' and is the RT difference between nonswitch (repeated) trials and single-task trials. That is, RTs are slower during an attention switching task, even when a switch is not required, compared to single-task RT (Monsell, 2003). This 'mixing' cost is understood to reflect the time cost imposed by the control processes involved in keeping two or more task/response sets active at the same time. Research has found both switching and mixing costs to be larger for older adults when compared with younger adults (Mayr & Liebscher, 2001; Meiran & Gotler, 2001; Meiran, Gotler, & Perlman, 2001; Kramer, Hahn, & Gopher, 1999), particularly when working memory load is increased (Kramer et al., 1994). These findings are taken to reflect the detrimental influence of increasing age on executive control processes involved in task switching, such as goal maintenance (de Jong, 2001), or inhibitory control of interference from distracting mental sets (Mayr & Liebscher, 2001) or response sets (Meiran & Gotler, 2001; Meiran et al., 2001).

Two main versions of the attention switching paradigm can be distinguished. In the first, uncued version, no forewarning regarding the upcoming switch is given, but the task either alternates every *n* trials, where *n* is constant and predictable, or a prespecified task sequence exists (Monsell, 2003). In the second, task-cueing paradigm, the task sequence is unpredictable and a cue is used to indicate a switch of task. The cue may be explicit, and precede stimulus presentation, or some aspect of the task itself, such as the type of stimulus, or mode of presentation forms the cue and indicates the requirement to change task. Both uncued and cued switches are a natural feature of interactive learning/working environments (e.g., following changes in the flow of speech/dialogue, human-computer interactions, etc.). However, it not yet known if the requirement to switch attention influences subsequent memory; this is important in light of age-differences in executive control.

Broadly speaking, learning involves the consolidation of new associations; it is dependent on the ability to sustain attention and optimal arousal, inhibit distraction and maintain goal-oriented focus (Anderson & Craik, 2000; Hasher, Zacks, & May, 2000; Robertson & Murre, 1999; Van Breukelen, 1995). Attention switching may be operative on a number of levels during the process of consolation of a memory trace.

For example, maintaining a goal-oriented focus by shifting attention away from distractions and toward target stimuli is fundamental to any encoding process. A common finding is that interference caused by distractions increases with age in adulthood, particularly during nonoptimal states of arousal (Hasher, Zacks, & May, 2000). Therefore, the requirement to switch attention from the *off-task* (distracted) to on-task (attentive) state may increase with age in adulthood to produce an overall reduction in learning time, an increase in distraction time, and a corresponding pattern of increased intraindividual variability in performance profiles (see Van Breukelen, 1995, for a RT model). This is consistent with research findings which demonstrate greater intraindividual variability for older adults when compared with younger adults (Myerson & Hale, 1993; Salthouse, 1993; Hertzog et al., 1992; Hultsch, McDonald, & Dixon, 2002; Rabbitt & Patrick, 2001; Rabbitt, Osman, Moore, & Stollery, 2001; Strauss et al., 2002). A similar pattern of increased intraindividual variability in the activation of, and movement between, two distinct *on-task* states demanded by an attention-switching paradigm may serve to disrupt learning. This is consistent with the suggestion that the increased switching and mixing costs observed for older, compared to younger, adults are due to older adults' difficultly maintaining clear and distinct representations of the currently relevant set when competing and potentially confusable sets exist in the same context (Mayr & Liebscher, 2001).

In relation to memory, an increase in *on-off* task attention switching may be disruptive for two reasons: (1) Target stimuli cannot be fully encoded during an *off-task* state and (2) the switch from *off-task* to *on-task* utilizes cognitive resources that may serve to support the strength, depth, or distinctiveness of an encoding process. Likewise, attention switching might influence memory performance when *on-task* mental set changes from one encoding process to another. For example, the mental set adopted may switch from shallow to deep levels of encoding (e.g., a focus on font color versus meaning of words presented serially). Two broad categories of *on-task* attention switch can be assumed: *internally* controlled and *externally* controlled. For internally controlled attention switches, the individual makes some decision about the mental set adopted and the frequency of movement from one mental set to another. For externally controlled switches (e.g., in a task-switching paradigm), some uncued or cued aspect of the stimulus environment defines the encoding process, frequency, and predictability of switching (see Figure 1). Either internally or externally controlled switching during encoding may influence later memory. For externally controlled manipulations, although the impact of shallow versus deep and incidental versus explicit encoding instructions on subsequent memory performance

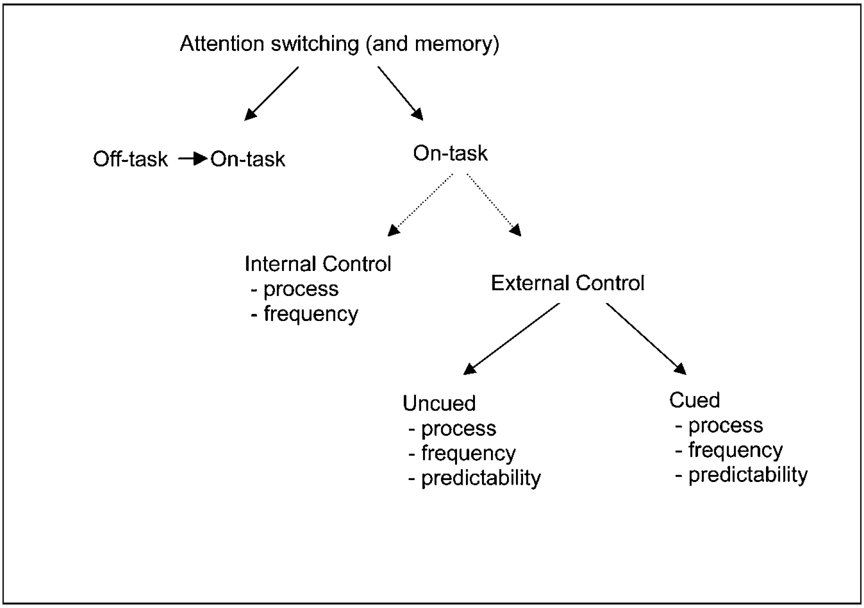

Figure 1. A general scheme of attention switching types and elements.

of younger and older adults has been investigated (Craik & Byrd 1982; Craik & Simon, 1980), the impact of switching itself has not.

The Current Study

The current study investigated the immediate and more delayed effects of changes in *on-task* mental set switching for subsequent memory. Two experiments were designed to examine the interaction between aging, attention switching, encoding process, and recognition memory using two different versions of the task-cuing attention switching paradigm. In Experiment 1, the task to be performed was cued by means of stimulus location, whereas in Experiment 2, all stimuli appeared centrally on the screen and the required task was precued. Rather than to enable comparisons of the effects of the different cue types, the rationale for Experiment 2 was to improve upon Experiment 1 in terms of experimental control and reliability of memory assessments (see below), and to isolate the residual component of switching cost by providing a long cue-target interval (see Meiran et al., 2001).

In both experiments, participants were asked to classify each of a series of words presented sequentially on a computer screen.

Participants switched between categorising words on the basis of a shallow stimulus characteristic (i.e., color), their semantic category (i.e., living/nonliving), and the performance of one of these two tasks along with the additional requirement to explicitly learn the words presented. Following the attention-switching task, participants were presented with a recognition memory task that tested recognition for a proportion of the words encountered during the encoding phase. This enabled the examination of recognition memory for words encoded either incidentally or explicitly during conditions of shallow processing or deep, semantic processing. Recognition, rather than free or cued recall, was chosen as the outcome memory measure, as it is established that baseline differences in performance between older and younger adults are greater in tests of recall than in tests of recognition (Balota, Dolan, & Duchek, 2000; Craik & McDowd, 1987), and we wished to minimize any such baseline differences in order to avoid an exaggeration of any age-related effects in memory.

In Experiment 1, participants were asked to switch to an alternate process every 7 trials on average (range 6–9). On each trial the required process was cued simultaneously with stimulus presentation by the location of the words. Recognition memory for the first six words after each attention switch was examined. In Experiment 2, all words were presented centrally on the computer screen, and participants were precued to switch attention to an alternate process every 4 trials on average (range 3–5). Experiment 2 examined recognition memory for the first three words after each attention switch.

Three contrasting hypotheses were proposed. First, on the basis of previous findings indicating that attention switching is attentionally demanding and disrupts older adults' RT performance to a greater extent than that of younger adults, the *full age effect* hypothesis proposed that the requirement to switch attention would disrupt older adults' encoding *and* memory to a greater extent than that of younger adults for those words presented immediately after a switch. Second, based on Anderson et al.'s (1998) finding that the executive demand of dividing attention at encoding disrupted memory performance equally for the both younger and older age groups, the *partial age effect* hypothesis proposed that attention switching, while reducing the relative *efficiency* (i.e., speed) with which stimuli are encoded, would not have such an effect on *efficacy* of the consolidation process and consequent retrieval, for older adults when compared with younger adults (see Eysenck, 1992, for detailed discussion on the distinction between efficiency and efficacy). In other words, any negative effects of attention switching on subsequent memory would be similar for both age-groups. Finally, the *null effect* hypothesis proposed that although resource demands during encoding increase when there is a requirement to switch attention, the memory trace for the new stimulus encountered after a switch is unaffected for both younger and older adults. This hypothesis is based on the assumption that an attention switch may act to update context and refresh an ongoing, and potentially habituated, mental set.

We also wished to explore whether or not any effects of switching on memory depended on the nature of encoding operation performed after switching had occurred. Given that older adults benefit more from semantic encoding and less from self-initiated learning instructions when compared to younger adults, we speculated that any disruption to memory caused by attention switching would be smaller for older adults when the tasks provided more environmental support and necessitated less self-initiated encoding.

EXPERIMENT 1

Method

Participants

Participants aged 60 to 80 years were recruited from five organizations for retirees and were paid 10 euros for participation. Thirty-five (mean age = 70.55 years, $SD = 6.33$, 22 females and 13 males) agreed to participate. The younger sample consisted of 30 undergraduate students (mean age = 22.06 years, $SD = 2.71$, 21 females and 9 males) who received course credit for their participation. Prospective participants were excluded if they were not right-handed, did not currently live independently in the community, suffered from any medical conditions associated with a head injury, limb injury, spinal injury, epilepsy, stroke, or heart attack, did not have English as a first language, were currently on antidepressant medication, sedatives or tranquilizers, or did not possess normal or corrected-to-normal vision and hearing.

The amount of formal education was significantly greater ($F(1, 64) = 35.21$, $p < .001$) in the younger group (mean = 16.83 years, $SD = 1.8$) than in the older adult group (mean = 12.29 years, $SD = 3.36$). However, no age-group differences were observed ($F(1, 64) = .09$, $p > .05$) when younger (mean = 37.60, $SD = 8.44$) and older (mean = 35.76, $SD = 8.19$) were compared on the National Adult Reading Test (NART; Nelson, 1982), a marker test for crystallized intelligence or cognitive pragmatics (Baltes, 1997).

Experimental Task

Tasks were presented on a 15-inch monitor interfaced with a Gateway E-4400 computer. Participants responded to the tasks with the 1 and 2 (encoding task) and 4 and 5 (recognition task) keys of the number pad on a standard keyboard using the right hand. Special labels marked the keys. The experimental task was designed and run on E-Prime (version 1.0) software. Stimulus presentation was synchronized with the video display refresh cycle, and RTs were recorded with greater than 1-ms accuracy. Each participant was seated comfortably with head approximately 18 inches from the centre of the computer screen.

Choice-RT encoding task. Using the display presented in Figure 2, participants were presented sequentially with 100 nouns at one of three screen locations. Words (50 animals and 50 nonliving concrete nouns) presented to each location were matched for word length and word frequency using the Brown Corpus (Francis & Kucera, 1982). For half of the words the font color was black, for the other half the font color was red. Font size was 18 point. Words remained on the screen for 3000 ms while participants responded as

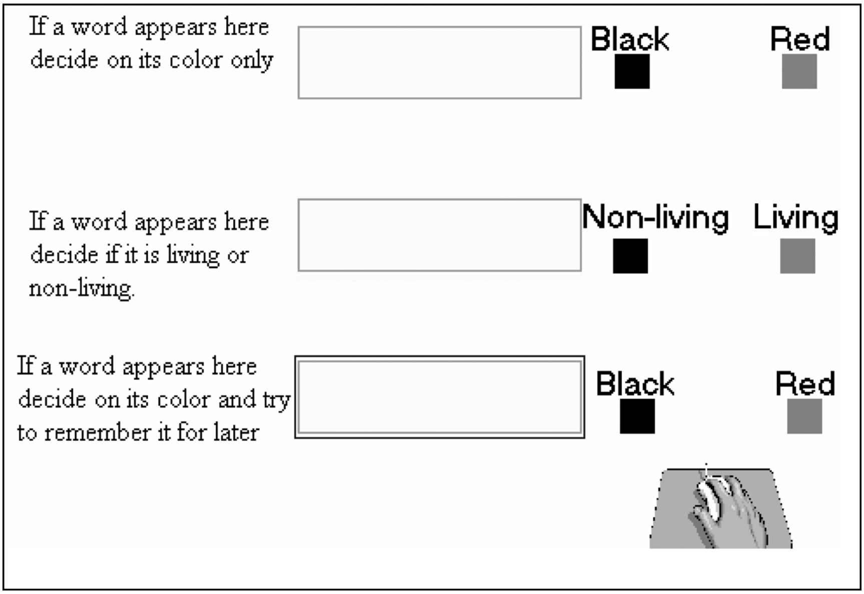

Figure 2. Experiment 1 computer display seen by participants during word classification.

fast and accurately as possible to the encoding requirements. Error feedback was provided by a bell ring (11 kHz), which sounded for 1000 ms. Participants were instructed to make one of three two-choice responses: (1) color decision (red/black), (2) semantic decision (living/nonliving), or (3) color decision (red/black) with explicit learning (i.e., memorize the word presented). Runs of 7 words on average (range 6–9) were presented sequentially for each type of encoding before attention was switched to a new type of encoding. Encoding instructions for each location remained on the screen throughout to support participants.

Over the experiment, participants processed four runs (lists) of each type of processing (i.e., a total of 12 lists). Switches occurred in a quasirandom order without any preparatory cue. A practice block consisting of 54 words with 10 switches was included to familiarize participants with the procedure and ensure that all encoding requirements, including the requirement to explicitly learn, were clearly understood (i.e., for Location 3, participants understood that they were being asked to remember the word and not its color). Two versions of the task were developed using the same words to counterbalance the encoding process and serial positions of words presented. In both versions, the first words presented after an attention switch were matched for word frequency.

Recognition task. Recognition memory was tested after a brief interval (during which recognition instructions were presented and participants prepared) for the first six words presented after an attention switch (i.e., 3 [processes] $\times$ 4 [replications] $\times$ 6[words] $=$ 72 targets). Seventy-two non-target words matched for word frequency and not previously presented to participants for encoding were also presented during the recognition test. Words were presented in blue font centrally on a white screen until the participant responded or for a maximum of 3000 ms. Participants were asked to decide if the word presented was a target or nontarget by pressing one of two keys on the keyboard. They were instructed that targets included both explicitly learned words and those seen but not explicitly learned during the experimental task.

Experimental Procedure

After informed consent had been obtained, an appointment with each participant was arranged. The test battery took approximately 40 to 60 min. to complete. Upon first arriving in the laboratory participants were administered the National Adult Reading Test (NART; Nelson, 1982) and were then introduced to the experimental task. A period of practice ensured that all participants understood the processing decision, explicit learning and switching requirements. The main experimental tasks were then administered. Participants were debriefed and thanked before leaving the laboratory.

Results

A series of $2 \times 3 \times 6$ mixed-factor analyses of variance (ANOVAs) were computed on the encoding RTs, encoding errors, and subsequent recognition memory (computed on the basis of hits–false alarms) for the 72 target words. The between subject factor was age group (younger and older). The within subject factors were encoding process (color, semantic, color-and-learn), and serial position (SP1 to SP6). Stimuli for which an error was made during the encoding task were excluded from the recognition analysis. Table 1 contains a summary of performance for younger and older adults for each process and serial position.

Choice-RT Encoding Task

Errors. Error rates were low. However, ANOVA revealed a significant age group differences, with older adults making more errors

Table 1. Proportion errors, RT means, and recognition memory performances of younger and older adults in Experiment 1

		Prop. errors		RT (ms)		Hits–false alarms	
Process	Serial position	Older	Younger	Older	Younger	Older	Younger
Color	1	0.093	0.000	1573	1145	0.258	0.391
	2	0.036	0.008	978	840	0.329	0.423
	3	0.057	0.016	997	771	0.229	0.463
	4	0.036	0.040	944	748	0.244	0.375
	5	0.029	0.008	978	769	0.272	0.407
	6	0.050	0.000	941	742	0.258	0.415
Semantic	1	0.121	0.000	1820	1323	0.429	0.560
	2	0.057	0.065	1141	1036	0.401	0.512
	3	0.071	0.048	1156	1032	0.415	0.471
	4	0.057	0.073	1234	1074	0.386	0.608
	5	0.043	0.024	1108	985	0.465	0.495
	6	0.029	0.032	1121	962	0.429	0.568
Color-and-learn	1	0.093	0.024	1752	1325	0.265	0.431
	2	0.057	0.032	1138	990	0.229	0.495
	3	0.064	0.024	1082	975	0.272	0.455
	4	0.050	0.000	1145	976	0.244	0.431
	5	0.043	0.000	1067	951	0.308	0.520
	6	0.029	0.024	1028	877	0.365	0.528

(5.7%) compared to younger adults (2.4%; $F(1, 64) = 4.52$, $p < .05$). There was a main effect for serial position (SP) with accuracy generally improving progressively from SP1 to SP6 ($F(5, 320) = 3.56$; $p < .01$). There was also an SP × Age Group interaction, with older adults tending to make more errors for SP1 (10.3%) compared to younger adults (0.9%; $F(5, 320) = 6.25$, $p < .001$; see Figure 3*a*).

Post hoc comparisons revealed that age differences in accuracy were accounted for largely by the difference between younger and older adults immediately after switching attention at SP1 ($F(1, 64) = 16.66$, $p < .001$). When response accuracy was compared for SPs 2 to 6, no significant age differences were observed ($p > .05$ for all five comparisons). A trend was observed in which older adults significantly improved in accuracy from Trial 1 to Trial 6 ($F(1, 64) = 29.20$, $p < .001$). No such trend was observed for younger adults ($F(1, 64) = 2.81$, $p > .05$).

Reaction times. There was a main effect for age group with older adults responding to the words more slowly than younger adults overall (mean young = 973 ms; mean older = 1177 ms;

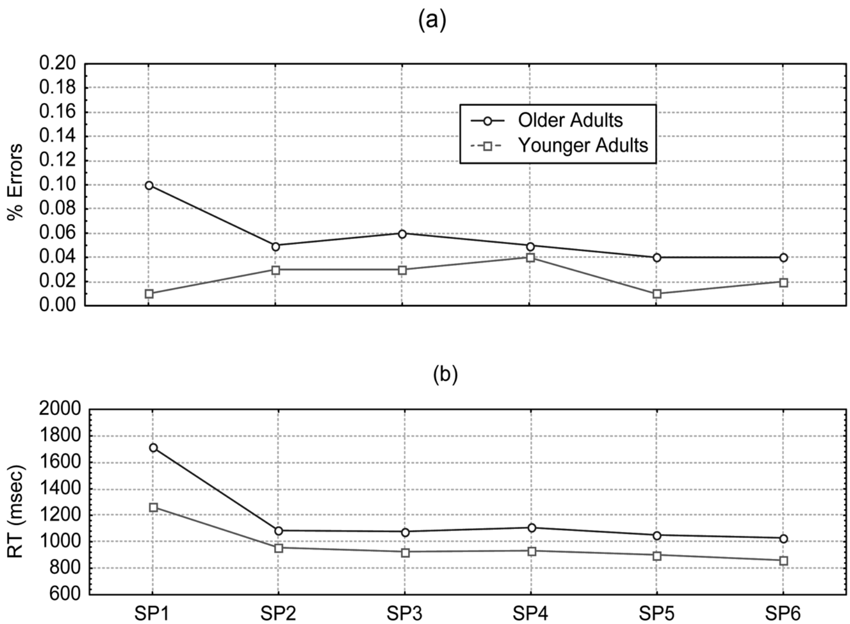

Figure 3. Experiment 1 encoding accuracy (*a*) and mean RT (*b*) across serial position for younger and older adults.

$F(1, 63) = 19.51$, $p < .001$). There was also a main effect for process ($F(2, 126) = 75.37$, $p < .001$). Responses to the semantic category of the word (mean = 1165 ms) were significantly longer than either responses to the color (mean = 952 ms; $F(1, 63) = 166.13$, $p < .001$) or responses to color with concurrent memorizing of the word (color-and-learn) (mean = 1108 ms; $F(1, 63) = 8.80$, $p < .01$). Responding to color-and-learn stimuli also took significantly longer than to color stimuli alone ($F(1, 63) = 74.70$, $p < .001$).

There was a main effect for serial position (SP; $F(5, 315) = 279.20$, $p < .001$), with SP1 (mean = 1489 ms) producing significantly slower RTs when compared to SPs 2 to 6 (means = 1020, 1002, 1020, 976, 945 ms, respectively, $p < .001$ for all five comparisons). There was also an Age $\times$ SP interaction ($F(5, 315) = 24.57$, $p < .001$) with older adults being more penalized at SP1 than younger adults. Post hoc analyses revealed that the difference in RT between younger and older adults at SP1 was large (mean old = 1714 ms, mean young = 1264 ms; $F(1, 63) = 72.64$, $p < .0001$), whereas differences for SPs 2 to 6 were smaller, yet still significant ($p < .01$ for each comparison, see Figure 3*b*).

There was also an SP $\times$ Process interaction ($F(10, 630) = 2.24$, $p < .05$). Post hoc analyses revealed that RT differences between semantic and colour and learn processes was non-significant for SP1 and SP2 combined ($F(1, 63) = 1.23$, $p > .05$), but a trend emerged for SP3 ($F(1, 63) = 6.35$, $p < .05$), SP4 ($F(1, 63) = 8.61$, $p < .01$), SP5 ($F(1, 63) = 1.43$, $p > .05$), and SP6 ($F(1, 63) = 9.80$, $p < .01$), with responses to semantic stimuli taking longer than color-and-learn stimuli. No higher order interactions were observed.

Recognition

Results indicated a main effect of age ($F(1, 64) = 18.00$, $p < .0001$) with younger adults remembering more than older adults overall (young mean = 47.4%, old mean = 32.2%). The was also a main effect of process ($F(2, 128) = 29.81$, $p < .0001$); words encoded under the semantic condition (mean = 47.8%) were better recognized than color encoding (mean = 33.8%; $F(1, 64) = 61.88$, $p < .0001$) or color-and-learn encoding (mean = 37.8%; $F(1, 64) = 25.54$, $p < .05$). However, compared with encoding on the basis of color alone, the instruction to explicitly learn words had a positive effect on memory ($F(1, 64) = 5.25$, $p < .05$).

The Age Group $\times$ Process interaction did not reach significance ($F(2, 128) = 2.41$, $p = .09$). However, whereas younger adults' memory benefited from the instructions to explicitly learn words compared to color encoding alone ($F(1, 64) = 6.44$, $p < .05$), older adults did not ($F(1, 64) = 0.41$, $p > .05$). Furthermore, compared with younger adults, older adults benefited more from semantic encoding than they did from instructions to explicitly learn words. Specifically, when younger and older adults were compared, the difference between the differences for semantic and color-and-learn encoding reached significance ($F(1, 64) = 3.90$, $p = .05$).

There was no main effect of SP ($F(5, 320) = 1.32$, $p > .05$), no age-Group × SP interaction ($F(5, 320) = .34$, $p > .05$), and no significant Process × SP interaction ($F(10, 640) = 1.40$, $p > .05$; see Figure 4).

Discussion

Consistent with previous research, results of Experiment 1 found that the requirement to switch attention has a more deleterious effect on response speed and accuracy of older adults when compared with younger adults. Specifically, the current study revealed significant Age Group × Serial Position interaction effects for both speed and accuracy during the choice-RT encoding task, largely accounted for by the difference between younger and older adults immediately after switching attention. These results are consistent with suggestions

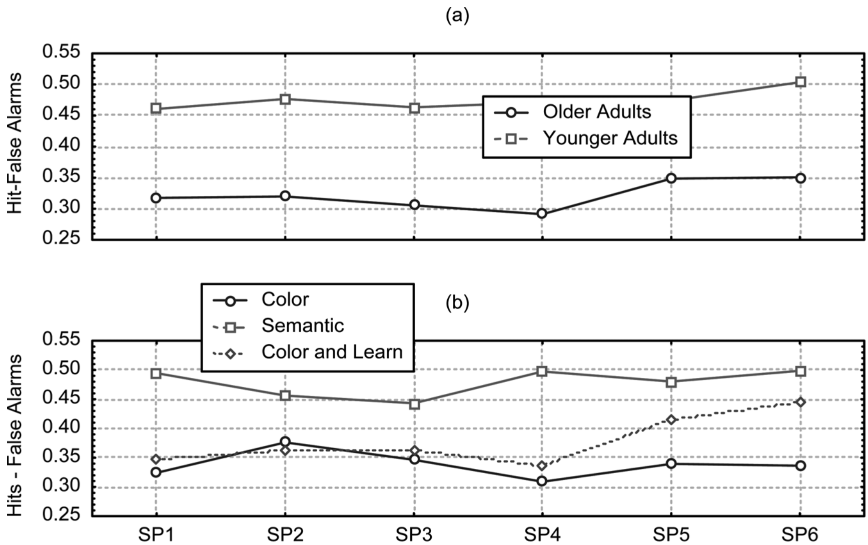

Figure 4. Experiment 1 recognition memory as a function of serial positions after an attention switch (*a*) for younger and older adults and (*b*) for three encoding processes.

by Anderson and Craik (2000) that age-related reductions in cognitive control act to reduce the availability of resources during demanding frontal lobe executive operations. Results also revealed that older adults' accuracy improved progressively after the demanding attention switch and was equal to that of younger adults almost immediately.

Although the level of processing had little effect on accuracy, it was generally the case that it took longer to respond to words on the basis of meaning than on the basis of color or color with concurrent learning (color-and-learn). On the other hand, the results showed that immediately after a switch (for Trials 1 and 2), there was no difference between semantic and color-and-learn performance. These findings suggest that the requirement to switch into the color-and-learn condition was sufficiently demanding to cause participants to slow down to the rate found in the semantic condition.

An examination of recognition memory for words encountered under these dynamic testing conditions showed that older adults suffered poorer recognition memory overall when compared with younger adults. In addition, the results indicated that older adults found it more difficult to self-initiate the encoding operations necessary for optimal memory. Specifically, compared with incidental memory for words classified on the basis of their color, younger adults' memory benefited from the additional intention to explicitly learn the words. Older adults did not show this same benefit, confirming previous research on age-differences in the benefits of self-initiated learning strategies on subsequent memory (Craik & Byrd, 1982; Craik & Simon, 1980).

On the other hand, results were also consistent with the hypothesis that more supportive encoding environments, which provide a context for deeper levels of processing, benefit older adults' memory and reduce age-differences in memory performance (Craik, 1983). Specifically, compared with younger adults, older adults benefited more from semantic encoding than they did from instructions to explicitly learn words.

Finally, attention switching did not have any significant effect on the recognition memory of either younger or older adults, supporting the *null effect* hypothesis. For words successfully encoded after a switch of attention, the encoding process adopted was the most important factor associated with consolidation of the memory trace; the executive requirement to switch mental set slowed the process of encoding considerably, but the knock-on effects on memory were not significant. That is, attention switching affected the efficiency, but not the efficacy of the encoding process. Although a null effect of attention switching on memory is an important finding, suggesting that an increase in executive control demands at encoding does not necessarily imply a negative effect on subsequent retrieval (see general discussion), Experiment 2 sought to develop a second testing paradigm that would supply additional control and power to the assessment.

EXPERIMENT 2

In Experiment 2, we set out to reexamine the effects of attention switching on age differences in encoding and retrieval of words using a precued version of the attention switching paradigm. In the precued version, words are presented sequentially at a central location. The use of a precued attention switching paradigm offers some advantages over the simultaneously cued paradigm when investigating effects of switching on memory. First, the precued paradigm helps to control for the effects of aging on eye-movement control (Nieuwenhuis et al., 2001) and avoid a potential confound between spatial location switching and mental set switching. Second, the precued paradigm enables the manipulation of the cue-target interval (CTI). The reduction in switch cost that results when a long CTI is provided is known as the 'preparation effect' (Monsell, 2003), as the time benefit is understood to be a measure of task preparation or task-set reconfiguration (Brass & von Cramon, 2002; Meiran, 1996; Monsell, 2003). The switch time cost remaining following a long CTI is known as the 'residual' cost (e.g., Meiran et al., 2001; Monsell, 2003). We therefore employed a long CTI in order to allow for an examination of the effects of the residual switch cost on the encoding process, rather than confounding preparation/reconfiguration and encoding. A CTI of 1200 ms was used as residual cost is not eliminated or reduced when CTI is increased beyond 600 ms (for discussion and analyses, see Allport, Styles, & Hsieh, 1994; Meiran, 1996; Strayer & Kramer, 1994; Rogers & Monsell, 1995; Meiran et al., 2001).

The critical trials in this version of the attention-switching and memory paradigm were Trials 1 to 3 after a switch with an average of 4 (range 3–5) trials before a process switch (see methods below). The primary reason for decreasing the average number of trials per run was to increase the number of words encoded at the critical serial positions from 12 to 18 so as to increase the reliability of recognition memory estimates. This modification was especially important for serial position (SP) 1, where error rates were higher than for other SPs in experiment 1. A corollary of this increase in the switch rate is that is was likely to increase executive demand (cf. Garavan, Ross, Lim, & Stein, 2000). In light of the null effect observed in Experiment 1, we believed that an increase in demand was not unwarranted; any negative effects of attention switching on memory, as originally conceived in the *full age effect* and *partial age effect* hypotheses, were assumed to be a function of executive demand. In total, although Experiment 1 and Experiment 2 differed in important respects, Experiment 2 was assumed to offer a more controlled, specific, and powerful method for evaluating the effects of attention switching on memory.

Experiment 2 predicted that greater reaction times (RTs) and error rates would be observed for switch trials compared to non-switch trials, and that this effect would be larger in older adults. If the *null-effect* hypothesis was confirmed, it would further support the conclusion drawn in Experiment 1 that attention switching effects the efficiency, but not the efficacy of the encoding process. Conversely, if the executive operation of switching interferes with subsequent memory, the *full age effect* hypothesis predicted that negative effects would be greater for older adults compared with younger adults, whereas the *partial age effect* hypothesis assumed a relative decrement for older adults compared with younger adults at encoding only, with equal negative effects for both age groups at retrieval. Finally, we predicted that semantic encoding would reduce age differences in memory, whereas self-initiated learning processes would increase age differences relative to shallow encoding.

Method

Participants

Participants were 24 older ($M = 70.0$, $SD = 6.22$) and 24 younger ($M = 19.5$, $SD = 1.35$) adults. Selection and exclusion criteria were the same as in Experiment 1. No participant tested in Experiment 2 had also participated in Experiment 1. The number of years of formal education was significantly greater ($F(1, 46) = 19.117$, $p < .01$) in the younger group ($M = 15.2$, $SD = .64$) than in the older adult group ($M = 12.5$, $SD = 2.9$). However, comparison of National Adult Reading Test scores (NART; Nelson, 1982) revealed no age-group differences ($F(1, 46) = .36$, $p > .05$) when younger ($M = 32.5$, $SD = 4.16$) and older ($M = 31.3$, SD $= 9.9$) adults were compared.

Experimental Task

The choice-RT and recognition tasks were administered and responses recorded using the same hardware and software set-up as in Experiment 1.

Choice-RT encoding task. Participants were presented with 131 words to encode. Words were either non-living or living (animal) concrete nouns, matched for word length and frequency using the Brown Corpus (Francis & Kucera, 1982). Half of both the living and nonliving nouns were presented in red font, the other half presented in black font. Font size was 18 point.

Participants were asked to attend and respond to one of the two dimensions of the stimuli: font color ('Color') or semantic category ('Meaning'). Stimulus words were presented for 3000 ms. Interstimulus interval (ISI) was 1200 ms during which time a central fixation was presented. Using the index and middle fingers of their right hand participants responded by pressing either a black or red key on the keyboard. Congruity between response key and font color during semantic encoding was controlled by having half of the words presented in the congruent font and half in incongruent font. The effects of congruity were statistically analysed but did not add to the interpretation of results and will not be discussed further here.

A task switch occurred every 4 trials on average (range 3–5). At switch, the cue 'COLOR' or 'MEANING' was presented centrally for 1000 ms, followed by the central fixation 'X' for 200 ms. At the same time, a nonverbal cue (**) was presented next to one of the visual, guidelines (Black/Red or Non-Living/Living) displayed on the screen (see Figure 5). This cue was displayed until a task switch when it was moved to a position next to the now-relevant task guideline. During both color and meaning encoding, for half the words at serial positions 1, 2, and 3 after a switch, a cue appeared above the target stimulus instructing participants to 'LEARN' the word. Cue onset was synchronous with presentation of the stimulus. All cues were blue in font color. Error feedback was provided by a bell ring (11 kHz), which sounded for 1000 ms. Trials exceeding 3000 ms were recorded as an error.

An alternate version of the task was constructed so that trials for which color encoding occurred in the first version were encoded under the meaning condition in the second version, and vice versa. Similarly, a counterbalanced ordering of the words was prepared in which different words were presented at serial positions 1, 2, and 3.

Recognition task. The recognition task testing memory for the first three words after each task switchcomprised 94 targets plus 94 nontargets. Stimuli were presented in blue fontcentrally on a white screen until the participant responded or for a maximum of 3000 ms. Participants were asked to decide if the word presented was a target or nontarget.

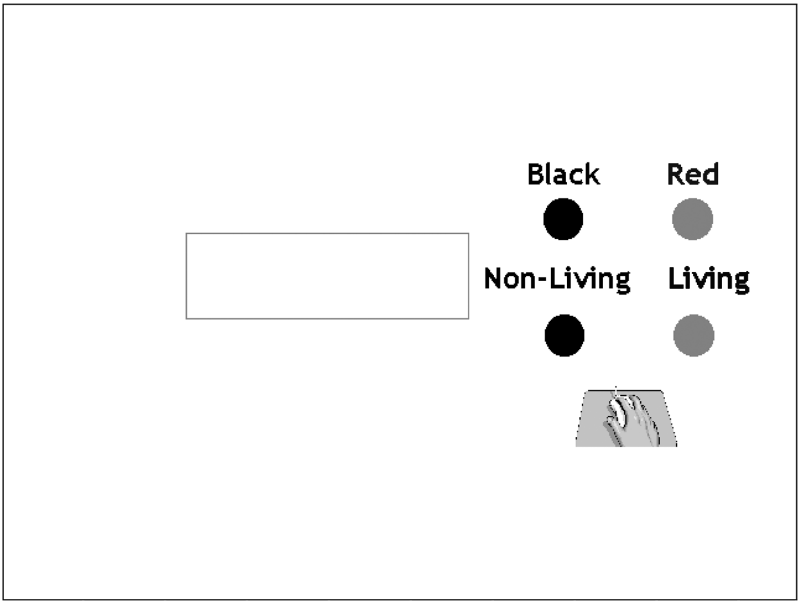

Figure 5. Experiment 2 computer display seen by participants during word classification.

Experimental Procedure

On arrival in the testing room, participants read and signed a consent form and competed the NART. Experimental task requirements were then explained in detail and the practice block of 20 trials was completed. Participants were instructed to respond as rapidly as possible while maintaining a high accuracy rate. Following the choice-RT task, instructions for the recognition task were presented; participants were asked to identify both explicitly learned words and those seen but not explicitly learned during the experimental task. Upon completion of the task, participants were debriefed and thanked.

Results

Average error rates, average reaction time (RT) and recognition accuracy (i.e., hits–false alarms) for serial positions 1, 2, and 3 were calculated for each participant. These data were submitted to a $2 \times 2 \times 2 \times 3$, mixed-factor analysis of variance (ANOVA). The one between-subjects factor, age group, had two levels (younger and older). Within-subject factors were process (color versus meaning encoding), Learn (explicit versus incidental learning), and serial position (SP1, SP2, and SP3). Stimuli for which an error was made during the encoding task were excluded from the recognition analysis. Table 2 presents a summary of descriptive statistics.

Choice-RT Encoding Task

Errors. Older adults made significantly more errors ($M = .094$) than younger adults ($M = .043$; $F(1, 46) = 13.28$, $p = .001$). There was a main effect for process, with more errors made for meaning ($M = .082$) than for color ($M = .055$; $F(1, 46) = 8.69$, $p < .01$). There was also a main effect for the instruction to learn ($F(1, 46) = 8.07$, $p < .01$); more errors were made during explicit learning ($M = .080$) compared with incidental learning ($M = .063$). There was a significant Learn × SP interaction (F(2, 92) = 3.76, $p < .05$); compared with incidental learning, participants made significantly more errors at SP2 ($F(1, 46) = 7.93$, $p < .01$) and SP3 ($F(1, 46) = 7.22$, $p < .01$) when asked to explicitly learn words. However, no such differences were observed at SP1.

Reaction times. Older participants were significantly slower ($M = 1384$ ms) than younger adults ($M = 1200$ ms; $F(1, 46) = 15.73$, $p < .001$). RTs were slower for meaning ($M = 1342$ ms) than for color stimuli ($M = 1242$ ms; $F(1, 46) = 31.86$, $p < .001$) and slower during explicit learning ($M = 1361$ ms) compared with incidental learning ($M = 1223$; $F(1, 46) = 42.04$, $p < .001$). A Learn × Age

Table 2. Performance measures for the switch task used in Experiment 2

Process	Learning	Serial position	Prop. errors Older	Prop. errors Younger	RT (ms) Older	RT (ms) Younger	Hits–false alarms Older	Hits–false alarms Younger
Color	Incidental	1	.054	.012	1320	970	.248	.390
		2	.036	.018	1292	1142	.295	.339
		3	.090	.018	1238	1086	.293	.313
	Explicit	1	.066	.042	1398	1162	.363	.553
		2	.143	.024	1358	1297	.343	.586
		3	.113	.052	1400	1243	.314	.623
Meaning	Incidental	1	.149	.060	1622	1147	.380	.480
		2	.083	.048	1268	1182	.426	.478
		3	.060	.060	1285	1122	.415	.492
	Explicit	1	.131	.036	1551	1278	.347	.661
		2	.083	.054	1411	1360	.466	.612
		3	152	.101	1469	1405	.379	.627

interaction ($F(1, 46) = 4.38$, $p < .05$) was accounted for by larger explicit versus incidental RT differences for younger adults ($M = 1291$ versus $M = 1108$; $F(1, 46) = 36.79$, $p < .0001$) compared to that for older adults ($M = 1431$ versus $M = 1337$; $F(1, 46) = 9.63$, $p < .01$). A Serial Position × Age interaction (F(2, 92) = 12.24, $p < .001$; see Figure 6*a*), was accounted for by the fact that older adults were significantly slower at SP1 compared to SP 2 ($F(1, 46) = 10.78$, $p < .01$) and SP3 ($F(1, 46) = 8.77$, $p < .001$), whereas younger adults were faster at SP1 compared to SP 2 ($F(1, 46) = 6.09$, $p < .001$) but not SP3 ($F(1, 46) = 3.02$, $p > .05$).

A significant Process × SP interaction was observed ($F(2, 92) = 7.33$, $p < .05$; see Figure 6*b*), with meaning encoding significantly slower than color encoding for SP1 ($F(1, 46) = 25.18$, $p < .0001$) and SP3 ($F(1, 46) = 10.56$, $p < .005$) but not for SP2 ($F(1, 46) = 1.60$, $p < .001$). Also, there was a significant Learn × SP interaction ($F(2, 92) = 3.73$, $p < .05$), with no significant differences in RTs across SPs ($p > .05$ for all three comparisons) during explicit learning; conversely, during incidental learning, responses became progressively faster following a switch, with the difference between SP1 and SP3 reaching significance ($F(1, 46) = 4.96$, $p < .001$).

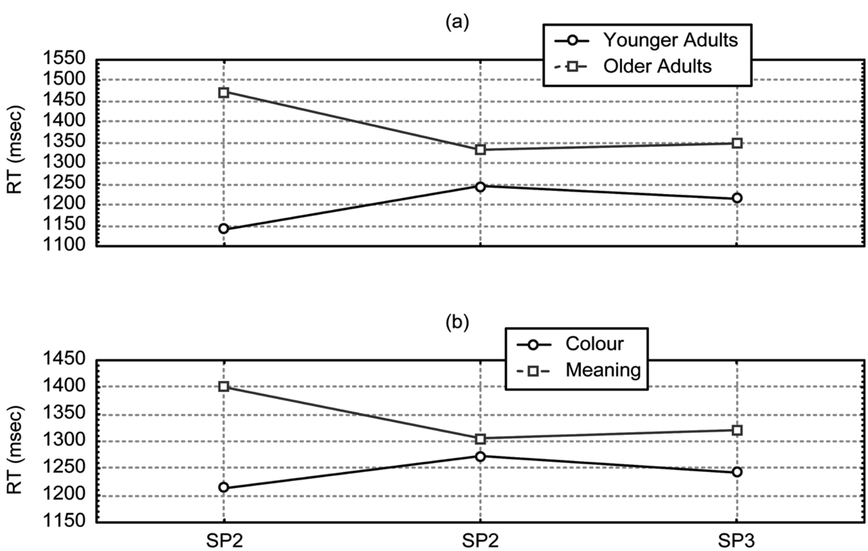

Figure 6. Experiment 2 mean RT (*a*) for younger and older adults and (*b*) for two encoding processes across three serial positions.

Recognition Task
Older adults remembered less ($M = .357$) than younger adults ($M = .513$; $F(1, 46) = 19.39$, $p < .001$). Words encoded under the meaning condition were better remembered ($M = .482$) than words encoded on the basis of color ($M = .385$; $F(1, 46) = 30.92$, $p < .001$). Participants also remembered more of what was explicitly learnt ($M = .489$) than what was incidentally learnt ($M = .381$; $F(1, 46) = 43.34$, $p < .001$). The main effect for SP was nonsignificant ($F(2, 92) = .346$, $p > .05$).

An Age $\times$ Learn interaction indicated that older adults did not benefit as much as younger from explicit learning instructions ($F(1, 46) = 27.16$, $p < .001$). For older adults the means for incidental and explicit conditions were 0.34 and 0.37, respectively; the corresponding figures for younger adults were 0.42 and 0.61, respectively. Post hoc analyses indicated that the difference between younger and older adults was non significant for words encoded incidentally ($F(1, 46) = 3.73$, $p > .05$), but highly significant for words explicitly encoded ($F(1, 46) = 33.35$, $p < .0001$). A significant Process $\times$ Learn interaction effect ($F(1, 46) = 10.33$, $p < .01$) indicated that memory for words encoded on the basis of color benefited more from explicit encoding (explicit – incidental, $F(1, 46) = 58.73$, $p < .0001$) than did words encoded on the basis of meaning (explicit – incidental, $F(1, 46) = 9.01$, $p < .005$).

The four-way Process $\times$ Learn $\times$ SP $\times$ Age Group interaction effect approached significance ($F(2, 92) = 2.93$, $p = 058$). A series of post hoc analyses revealed two interesting trends of relevance. First, for words encoded on the basis of meaning and explicit learning, older adults tended to remember fewer words at SP1 ($M = .347$) compared to SP2 ($M = .466$; $F(1, 46) = 3.75$, $p = .058$), whereas younger adults showed the reverse trend ($M = .661$ and .612 for SPs 1 and 2, respectively; $F(1, 46) = .626$, $p > .05$). Conversely, for words encoded on the basis of color and explicit learning, there was a trend for younger adults' memory to improve from SP1 to SP3 whereas older adults' memory declined ($F(1, 46) = 3.36$, $p = .07$; see Table 2 for means).

Discussion

The results of Experiment 2 both complement and contrast with those of Experiment 1. Like Experiment 1, older adults made more errors and were slower to respond during the choice-RT encoding task when compared with younger adults. Older adults tended to respond more slowly at serial position 1 (SP1) relative to SPs 2 and 3;

however, unlike Experiment 1, younger adults showed the reverse trend. We suggest that the long preparation interval (provided by the long CTI) allowed younger adults to attain complete reconfiguration of task set prior to the presentation of the stimulus (see De Jong, 1999, 2001; Monsell, Yeung, & Azuma, 2000), whereas older adults, due to reduced cognitive resources, were unable to complete this advance reconfiguration and displayed the typical residual switch cost. Residual switch cost is not generally eliminated beyond a preparation interval of 600 ms (cf. Allport et al., 1994). In the current experiment, a CTI of 1200 ms was adopted in order to ensure that any costs observed were manifestations of the residual, as opposed to preparatory cost. However, this manipulation was confounded by the fact that stimuli, instead of terminating on response, remained on screen for 3000 ms, necessary to ensure equal stimulus encoding time for both older and younger adults. Given that average RTs were approximately 1200 ms for younger and 1400 ms for older adults, the response-target interval (RTI) was closer to 3000 ms. We suggest that the combination of precueing, the considerable RTI, and constant visual aids during switch-task performance enabled a level of preparation/reconfiguration that was greater than in any previous experiment. We suggest that the degree of preparation/reconfiguration of task and response sets attained by the younger participants in Experiment 2 was such that the new stimulus dimension at SP1 conveyed a processing advantage over subsequent SPs and was responsible for the novel results we observed.

In general, participants made more errors and were slower when asked to respond to meaning versus color or when asked to explicitly learn words versus incidental encoding. Younger adults took longer to respond when they were asked to explicitly learn words compared to incidental encoding; older adults did not show this difference in response times. This result is interesting as it suggests that older adults may not have made appropriate use of the time available to initiate explicit learning operations. This in turn might explain why younger adults' memory benefited more than older adults' from the instruction to learn.

Another interesting finding was that serial position had no effect on RT for words encoded under explicit learn instructions; conversely, RTs to incidentally learned stimuli were slower at SP1 compared to later serial positions. In other words, although the typical RT cost of attention switching was observed for incidentally learned stimuli, no pattern was observed for explicitly learned stimuli. This finding suggests that when given a cue to learn, and sufficient time to prepare, explicit learning is a demand that is not altered by the requirement to switch. One explanation is that explicit learning instructions produce a more complete and consistent reconfiguration of mental set, calling upon a strategy of encoding that is more resilient to competing demands or the residual effect of a previous mental set.

Serial position did not have any detrimental effect on older adults' accuracy; ensuring that comparisons of recognition memory performance across serial position were based on similar numbers of correctly encoded words. Although both younger and older adult's memory benefited from semantic encoding, only younger adults benefited from the instruction to explicitly learn, thus replicating the pattern observed in Experiment 1. Although younger adult's memory performance was better than that of older adults, the difference was large and significant for words encoded explicitly, but small and nonsignificant for words encoded incidentally. Again, these results support Craik's (1983) contention that self-initiated effortful encoding situations produce the largest age differences in memory performance.

Attention switching had no obvious differential effect on the memory performance of younger or older adults. However, two contrasting trends involving the interaction between encoding process, attention switching and aging were suggestive. First, older adults tended to remember fewer words processed on the basis of *meaning* and explicit learning immediately after a switch when compared with the subsequent trial (i.e., SP2), whereas younger adults showed the reverse trend. It is suggested that the meaning decision, combined with explicit learning was the most attentionally demanding condition, and a switch into this condition therefore penalized older adults, who suffer reduced processing resources, to a greater extent than younger adults. Second, for words encoded on the basis of *color* and explicit learning, younger adult's memory improved, whereas older adult's memory declined, after switching attention. In this case, an attention switch may have helped to activate (initiate or refresh) a less effective explicit learning strategy for older adults, while interfering with an already effective explicit learning strategy used by younger adults.

Overall, the results of Experiment 2 are consistent with those of Experiment 1 in demonstrating larger attention switching costs and poorer ability to self-initiate learning processes during encoding for older compared with younger adults, but also in failing to provide strong support for an effect of attention switching on memory. Nonetheless, the findings suggest a number of avenues for future investigation.

GENERAL DISCUSSION

Taken together, the results of Experiments 1 and 2 confirm previous findings (e.g., Meiran et al., 2001; Kramer et al., 1999; De Jong, 2001) that attention switching impacts on task performance of older adults to a greater extent than that of younger adults. Even when given 1200 ms of preparation time in Experiment 2, older adults suffered residual switch costs associated with attention switching. This is consistent with the hypothesis that the amount of attentional resources available to fuel complex cognitive tasks is reduced by aging and as a result of cognitively demanding processes such as attention switching. These demands deplete a greater proportion of available resources in older than in younger adults, resulting in poorer performance (e.g., Anderson & Craik, 2000; Craik & Simon, 1980; Craik & Byrd, 1982; Craik, 1983). As noted in the introduction, older adults have been shown to suffer considerably enlarged 'mixing' costs relative to younger adults (Mayr & Liebscher, 2001; Meiran & Gotler, 2001; Meiran et al., 2001). The current study did not, however, include a single-task control, precluding the examination of mixing costs and the possibility that greater age-related effects may have been observed had we examined mixing cost. The impact of mixing cost in a paradigm such as those employed in the current study merits further investigation.

With regard to the impact of aging on memory, this study provides clear support for the hypothesis that orienting older adults towards deeper levels of processing can benefit their encoding operations and lead to improved memory (Craik, 1983). Furthermore, the results corroborate the finding that older adults, unlike younger adults, do not spontaneously engage in deep processing when given the instruction to self-initiate their own learning strategy, demonstrated by a failure to show any difference in memory for words learned incidentally and explicitly. These findings have clear implications for the organisation of older adults' task space and environment. They suggest, for example, that the requirements to switch between multiple tasks are best minimized. In general, memory tasks that involve automatic or well-practiced operations and environmental support should make deeper levels of processing available and accessible.

On the other hand, Experiments 1 and 2 did not provide strong support for the idea that the age-related decrement in processing *efficiency* for words presented immediately after an attention switch is associated with a decrement in encoding *efficacy* for those words, as would be demonstrated by a concomitant decrement in subsequent recognition memory. The only suggestion of such an effect came in Experiment 2 for words encoded in the meaning and explicit learning condition—older adults tended to remember fewer words at SP1 compared to SP2, whereas younger adults showed the reverse trend. However, for words encoded on the basis of color and explicit learning, there was a trend for younger adults' memory to improve from SP1 to SP3 whereas older adults' memory declined. These results suggest that although attention switching may be a resource-demanding process, under certain circumstances the reconfiguration process may have either a positive or negative effect on memory.

One caveat concerns our use of a recognition task as the memory outcome measure. Given that recognition depends substantially on familiarity (e.g., Jacoby, 1991; see Yonelinas, 2002, for a review of theoretical models), the absence of task-switch effects on recognition are perhaps understandable. Although attention switching may have acted to impair recall by affecting the encoding of information, it may have had less impact on familiarity-based judgements (recognition). Automatic memory processes such as familiarly are known not to be affected by aging to the same degree as controlled memory processes such as recollection, which underlies recall (e.g., Jacoby, Jennings, & Hay, 1996; Jennings & Jacoby, 1993). Had we used recall as a measure of memory, larger effects may have been observed. Nonetheless, in focusing on the effects of attention switching on memory, we had wished to minimize baseline differences in performance between older and younger adults associated with lack of environmental support in the retrieval context in order to avoid an exaggeration of any age-related effects in memory.

The differential effects of attention switching during different encoding processes provide some clues as to the dynamic relation between aging, attention switching, and memory. For example, a mixed pattern of results concerning younger adults and attention switching performance costs were observed—Experiment 1 showed a switch cost for both age-groups, whereas Experiment 2 revealed a switch cost for older adults only, with a slight benefit of switching on younger adults' RT performance. We discussed this novel finding in terms of the considerable response-target interval that was produced through a combination of a 1200-ms cue-target interval, a 3000 ms stimulus presentation time, and the additional benefit of on-screen visual aids. We suggested that these factors enabled younger, but not older adults, to complete the reconfiguration processes required for task switching, thereby eliminating the switch cost. Older adults, on the other hand, were apparently unable to complete such processes and showed the typical residual switch cost.

Furthermore, it is possible that the long RTI had an effect on the mnemonic demands of the task, resulting in the failure to observe detrimental effects of attention switching on memory. A more demanding paradigm may be successful in producing the hypothesised memory decrements.

On the other hand, executive demand was clearly observable for older adults, who did show an effect of switching during choice-RT performance in both experiments. Furthermore, in Experiment 2, the interactive effects of demand and switching on retrieval were suggested by a trend for older adults, but not younger adults, to be penalized at SP1 compared to SP2 when asked to explicitly learn words while encoding their meaning. Future studies examining this issue will have to address questions of general versus specific effects of executive demands and attention switching on memory. Of particular relevance here may be the impact of mixing cost, as dicussed above.

Anderson et al. (1998) found that the executive demand of dividing attention at encoding disrupted retrieval for both a young and old age group equally, whereas the current study found no effect of attention switching on subsequent retrieval. Attention switching was seen to consistently interfere with older adults' performance on the choice-RT encoding task only. A caveat remains, however: as older adults are more likely to make more encoding errors after an attention switch (see Experiment 1), this may disrupt consequent memory for these stimuli. Unfortunately, as we cannot know what older adults were actually doing when they made an error, and given that younger adults made so few errors, no reasonable comparison of recognition memory performances for error stimuli could be conducted. Future studies, using a combined continuous recognition and attention switching paradigm could examine this issue more closely by looking at (ex-)gaussian RT distributions and errors simultaneously in an effort to classify errors into *off-task* and perseverative errors.

Although it might be assumed that attention switching could offer an opportunity to refresh a less engaged mental set, older adults did not switch into effective learning strategies spontaneously, as demonstrated by their failure to show any difference in memory for words learned incidentally and explicitly. Considering the likely involvement of the frontal lobe in the pattern of age differences observed (cf. West, 1996; Anderson & Craik, 2000), rehabilitative efforts should be considered in terms of their possible applications to older adults, who may benefit from attempts to compensate for organically-based executive control deficits.

For example, older adults are capable of improving their performance in dual and switch tasks with practice, and have demonstrated successful transfer of training on these paradigms to novel situations

(Kramer, Larish, & Strayer, 1995; Kramer et al., 1999). This demonstrates that executive control decrements in older adults are flexible and open to improvement, given the right strategies and training structure. Furthermore, older adults have considerable residual memory function that they are able to use with more efficiency when given appropriate training and support (see Anschutz, Camp, Markley, & Kramer, 1985; Craik, Byrd, & Swanson, 1987; Einstein & McDaniel, 1997; Jacoby et al., 1996; Yesavage, 1983, 1984; West, Crook, & Barron, 1992; Wahlin, Backman, & Winblad, 1995; for reviews see West, 1995; Glisky & Glisky, 1999). A training paradigm that combines memory and executive training by providing older adults with the opportunity to develop the skill of switching into effective learning strategies may help to ameliorate the negative effects of a failure to self-initiate learning. In fact, it may be that the core skill involved in self-initiated learning is the ability to switch seamlessly from an *off-task* to an *on-task* state that focuses on encoding stimuli deeply (e.g., based on meaning, context, source, association, etc.). Training studies that focus on optimising the ability to switch into a deep encoding state will benefit from a closer examination of the relation between attention switching and memory across a broad range of experimental settings.

Finally, the attention-switching paradigm employed in this study suggests that the effects of age-related executive control deficits on memory in older adults may be limited in some regards. Specifically, whereas executive deficits in attention switching were clearly demonstrated during encoding, effects on retrieval were limited. Clearly, executive control influences on memory must be elaborated further, and models of memory and aging memory should expand conceptualisations of executive control to include specification of the role of attention switching. As a novel approach to research in the area of aging cognition, the attention-switching and memory paradigms may prove to be fruitful in both the investigation of current hypotheses and the generation of new theories regarding the everyday cognitive problems experienced by older adults.

REFERENCES

Allport, A., Styles, E. A., & Hsieh, S. (1994). Shifting intentional set: Exploring the dynamic control of tasks. In C. Umilta & M. Moscovich (Eds.), *Attention and performance XV. Conscious and nonconscious information processing* (pp. 421–452). Cambridge, MA: MIT Press.

Anderson, N. D. & Craik, F. I. M. (2000). Memory in the aging brain. In E. Tulving & F. I. M. Craik (Eds.), *The Oxford handbook of memory* (pp. 421–452). Oxford: Oxford University Press.

Anderson, N. D., Craik, F. I. M., & Naveh-Benjamin, M. (1998). The attentional demands of encoding and retrieval in younger and older adults: 1. Evidence from divided attention costs. *Psychology and Aging, 13*, 405–423.

Anschutz, L., Camp, C. J., Markley, R. P., & Kramer, J. J. (1985). Maintenance and generalization of mnemonics for grocery shopping by older adults. *Experimental Aging Research*, *11*, 157–160.

Baddely, A. (1986). *Working memory.* Oxford: Oxford University Press.

Balota, D. A., Dolan, P. O., & Duchek, J. M. (2000). Memory changes in healthy older adults. In E. Tulving & F. I. M. Craik (Eds.), *The Oxford handbook of memory* (pp. 395–409). Oxford: Oxford University Press.

Brass, M. & von Cramon, Y. (2002). The role of the frontal cortex in task preparation. *Cerebral Cortex*, *12*, 908–814.

Craik, F. I. M. (1977). Age differences in human memory. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (pp. 384–420). New York: Van Nostrand Reinhold.

Craik, F. I. M. (1983). On the transfer of information from temporary to permanent memory. *Philosophical Transactions of the Royal Society of London Series B*, *302*, 341–359.

Craik, F. I. M. & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behaviour*, *11*, 671–684.

Craik, F. I. M. & Simon, E. (1980). Age differences in memory: The roles of attention and depth of processing. In L. W. Poon, J. L. Fozard, L. S. Cermak, D. Arenberg, & L. W. Thompson (Eds.), *New directions in memory and aging: Proceedings of the George A. Talland Memorial Conference* (pp. 95–112). Hillsdale, NJ: Erlbaum.

Craik, F. I. M. & Byrd, M. (1982). Aging and cognitive deficits: the role of attentional processes. In F. I. M. Craik & S. Trehub (Eds.), *Aging and cognitive processes* (pp. 191–211). New York: Plenum.

Craik, F. I. M. & McDowd, J. M. (1987). Age differences in recall and recognition. *The Journal of Experimental Psychology: Learning, Memory and Cognition*, *13*, 474–479.

Craik, F. I. M. & Anderson, N. D. (1999). Applying cognitive research to the problems of aging. In A. Koriat & D. Gopher (Eds.), *Attention and performance XVII* (pp. 583–615). Cambridge, MA: MIT Press.

Craik, F. I. M., Byrd, M., & Swanson, J. M. (1987). Patterns of memory loss in three elderly samples. *Psychology and Aging*, *2*, 79–86.

De Jong, R. (1999). An intention-Activation account of residual switch costs. In S. Monsell & Driver (Eds.), *Control of cognitive processes: Attention and performance XVIII* (pp. 358–376). Cambridge, MA: MIT Press.

De Jong, R. (2001). Adult age differences in goal activation and goal maintenance. *European Journal of Cognitive Psychology*, *13*, 71–89.

Duncan, J. (1995). Attention, intelligence and the frontal lobes. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 721–733). Cambridge, MA: MIT Press.

Einstein, G. O. & McDaniel, M. A. (1997). Aging and mind wandering: Reduced inhibition in older adults? *Experimental Aging Research*, *23*, 343–354.

Francis, W. N. & Kucera, H. (1982). *Frequency analysis of English usage.* Boston: Houghton Mifflin.

Garavan, H., Ross, T. J., Lim, S.-J., & Stein, E. A. (2000). A parametric manipulation of central executive functioning using fMRI. *Cerebral Cortex*, *10*, 585–592.

Glisky, E. L. & Glisky, M. L. (1999). Memory Rehabilitation in the elderly. In D. T. Stuss, G. Winocur, & I. H. Robertson (Eds.), *Cognitive Neurorehabilitation* (pp. 347–361). New York: Oxford University Press.

Hasher, L., Zacks, R. T., & May, C. P. (1999). Inhibitory control, circadian arousal and age. In A. Koriat & D. Gopher (Eds.), *Attention and performance XVII* (pp. 653–675). Cambridge, MA: MIT Press.

Jacoby, L. L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory and Language*, *30*, 513–541.

Jacoby, L. L., Jennings, J. M., & Hay, J. E. (1996). Dissociating automatic and consciously controlled processes: Implications for diagnosis and rehabilitation of memory deficits. In D. J. Herrman, C. McEvoy, C. Hertzog, P. Hertel, & M. K. Johnson (Eds.), *Basic and applied memory research: Theory in context* (pp. 161–193). Maywah, NJ: Lawrence Erlbaum.

Jennings, J. M. & Jacoby, L. L. (1993). Automatic versus intentional uses of memory: Aging, attention and control. *Psychology and Aging*, *8*, 283–293.

Kausler, D. H. (1994). *Learning and memory in normal aging*. San Diego: Academic Press.

Kramer, A. F., Hahn, S., & Gopher, D. (1999). Task coordination and aging: Explorations of executive control processes in the task-switching paradigm. *Acta Psychologica*, *101*, 339–378.

Kramer, A. F., Larish, J. F., & Strayer, D. L. (1995). Training for attentional control in dual task settings: A comparison of young and old adults. *Journal of Experimental Psychology: Applied*, *1*, 50–76.

Light, L. L. (1991). Memory and aging—four hypotheses in search of data. *Annual Review of Psychology*, *42*, 333–376.

Mayr, U. & Liebscher, T. (2001). Is there an age deficit in the selection of mental sets? *European Journal of Cognitive Psychology*, *13*, 47–69.

Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *22*, 1423–1442.

Meiran, N. & Gotler, A. (2001). Modelling cognitive control in task switching and aging. *European Journal of Cognitive Psychology*, *13*, 165–186.

Meiran, N., Gotler, A., & Perlman, A. (2001). Old age is associated with a pattern of relatively intact and relatively impaired task-set switching abilities. *Journal of Gerontology: Psychological Sciences*, *56B*, 88–102.

Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences*, *7*, 134–140.

Monsell, S., Yeung, N., & Azuma, R. (2000). Reconfiguration of task set: Is it easier to switch to the weaker task? *Psychological Research*, *63*, 250–264.

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

Posner, M. I. & Peterson, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience*, *13*, 25–42.

Rabbitt, P. M. A., Lowe, C., & Shilling, V. (2001). Frontal tests and models for cognitive ageing. *European Journal of Cognitive Psychology*, *13*, 5–29.

Rogers, R. D. & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General*, *124*, 207–231.

Salthouse, T. (1996). The processing speed theory of adult age differences in cognition. *Psychological Review*, *103*, 403–428.

Shalliu, T. (1988). *From neuropsychology to mental structure.* Cambridge, England: Cambridge University Press.

Shallice, T. (1994). Multiple levels of control processes. In C. Umilta & M. Moscovich (Eds.), *Attention and performance XV. Conscious and nonconscious information processing* (pp. 395–420). Cambridge, MA: MIT Press.

Shimamura, A. P. (1995). Memory and frontal lobe function. In M. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 803–813). Cambridge, MA: MIT Press.

Smith, A. D. (1996). Memory. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging*. San Diego, CA, London: Academic Press.

Wahlin, A., Backman, L., Winblad, B. (1995). Free recall and recognition of slowly and rapidly presented words in very old age: A community-based study. *Experimental Aging Research*, *21*, 251–271.

West, R. (1995). Compensatory strategies for age-associated memory impairment. In A. Baddeley, B. Wilson, & F. Watts (Eds.), *Handbook of memory disorders* (pp. 482–500). Chichester, UK: John Wiley & Sons.

West, R. L., Crook, T. H., & Barron, K. L. (1992). Everyday memory performance across the life span: Effects of age and noncognitive individual differences. *Psychology and Aging*, *7*, 72–82.

West, R. L. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychological Bulletin*, *120*, 272–292.

Yesavage, J. A. (1983). Imagery pretraining and memory training in the elderly. *Gerontology*, *29*, 271–275.

Yesavage, J. A. (1984). Relaxation and memory training in 39 elderly patients. *American Journal of Psychiatry*, *141*, 778–781.

Yonelinas, A. P. (2002). The nature of recollection and familiarity: A review of 30 years of research. *Journal of Memory and Language*, *46*, 441–517.