Neuropsychology
2004, Vol. 18, No. 3, 514–525

0894-4105/04/$12.00 DOI: 10.1037/0894-4105.18.3.514

Contribution of Frontal and Temporal Lobe Function to Memory Interference From Divided Attention at Retrieval

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On the basis of their scores on composite measures of frontal and temporal lobe function, derived from neuropsychological testing, seniors were divided preexperimentally into 4 groups. Participants studied a list of unrelated words under full attention and recalled them while concurrently performing an animacy decision task to words, an odd-digit identification task to numbers, or no distracting task. Large interference effects on memory were produced by the animacy but not by the odd-digit distracting task, and this pattern was not influenced by level of frontal or temporal lobe function. Results show associative retrieval is largely disrupted by competition for common representations, and it is not affected by a reduction in general processing resources, attentional capacity, or competition for memory structures in the temporal lobe.

Demonstrations within a laboratory setting of a debilitating effect of divided attention (DA) on retrieval have been variable and sometimes difficult to achieve. This has been unexpected, as most people allege that retrieving information from memory, be it the name of a movie, familiar face, or answer to an exam question, is an effortful task, often thwarted by distraction.

In this article, we seek to understand the variable effects of attentional manipulations on retrieval by examining the contribution of the frontal lobe (FL) and medial temporal lobe (MTL) in mediating interference from DA at retrieval. Specifically, we compare predictions from a neuropsychological model of memory and a general resource model by examining memory interference in a population of older adults classified by level of ability on tests sensitive to frontal and temporal lobe function. We begin by reviewing literature pertinent to our current understanding of episodic memory retrieval. We then discuss how researchers can use the dual-task technique to infer the processes necessary for retrieval by measuring the occurrence and extent of interference effects from a concurrently performed task.

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Additional materials are on the Web at http://dx.doi.org/10.1037/0894-4105.18.3.514.supp.

This research was supported by postdoctoral and graduate scholarships from the National Sciences and Engineering Research Council of Canada (NSERC) awarded to Myra A. Fernandes and Patrick S. R. Davidson, respectively; by Grant AG14792 from the National Institute on Aging awarded to Elizabeth L. Glisky; and by a grant from NSERC awarded to Morris Moscovitch. We thank Malcolm Binns for statistical consultation.

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Memory theorists have suggested that encoding and retrieval are similar or even identical, and they postulate a substantial overlap between the two processes. Craik (1983) proposed that encoding processes are mainly those involved in perceiving and comprehending information, and retrieval processes operate in reinstating the same pattern of cognitive activity as at encoding. Tulving's (1983; Tulving & Thomson, 1973) encoding specificity principle, the transfer-appropriate processing theory (Morris, Bransford, & Franks, 1977; Roediger, Weldon, & Challis, 1989), and Kolers's (1973) proceduralist view also embody the notion that retrieval processes must reflect the operations that were carried out during encoding; hence the two are linked.

Neuroimaging and lesion studies converge on the idea that the same neural pathways activated when information is perceived and encoded are again reactivated when that information is recovered from memory (Mishkin & Appenzeller, 1987; Moscovitch, Kapur, Köhler, & Houle, 1995; Nyberg et al., 1995; Squire, Cohen, & Nadel, 1984). There are, however, indications that some brain regions are specifically active during one process and not during the other. For example, in young adults, the left prefrontal region has been consistently shown to be involved in encoding, whereas the right prefrontal region is more involved during retrieval (Nyberg, Cabeza, & Tulving, 1996; Tulving, Kapur, Craik, Moscovitch, & Houle, 1994; but see Wagner et al., 1998, who found that for both encoding and retrieval, inferior prefrontal activation was lateralized on the basis of material type rather than on the basis of mnemonic operation; see also, Raye, Johnson, Mitchell, Nolde, & D'Esposito, 2000, who suggested that retrieval may require interhemispheric interactions). Although there has been work showing that the right prefrontal cortex (PFC) is involved in encoding of nonverbal materials, such as unfamiliar faces (Kelley et al., 1998; Wagner et al., 1998), the majority of studies indicate that encoding and retrieval activations are greater in opposite hemispheres. This work shows that the PFC is involved in retrieval but that the left and right hemispheres contribute differently at encoding and retrieval.

Once can use the DA technique to infer the processes required for a task by measuring the magnitude of interference from various concurrent tasks. With respect to attentional manipulations, it is well known that encoding is greatly affected when attention is divided, leading to poor memory (N. D. Anderson, Craik, & Naveh-Benjamin, 1998; Baddeley, Lewis, Eldridge, & Thomson, 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Murdock, 1965; Naveh-Benjamin, Craik, Guez, & Dori, 1998). A different story emerges when the attentional manipulation is introduced only at retrieval. Some studies demonstrated an interference effect on memory from DA at retrieval (Dywan & Jacoby, 1990; Fernandes & Moscovitch, 2000, 2002, 2003; Moscovitch, 1994; Park, Smith, Dudley, & Lafronza, 1989; Rohrer & Pashler, 2003), but most other studies have found little if any indication of a deleterious effect (N. D. Anderson et al., 1998; Baddeley et al., 1984; Craik et al., 1996; Kellog, Cocklin, & Bourne, 1982; Naveh-Benjamin et al., 1998). Thus, the evidence to date demonstrates that memory performance is much more affected by DA at encoding than DA at retrieval.

Several researchers have also examined performance on the concurrent, distracting task for clues as to the processes required for retrieval (N. D. Anderson et al., 1998; Craik et al., 1996; Fernandes & Moscovitch, 2000, 2002, 2003; Griffith, 1976; Johnston, Greenberg, Fisher, & Martin, 1970; Johnston, Griffith, & Wagstaff, 1972; Naveh-Benjamin et al., 1998; Trumbo & Milone, 1971). They have shown that retrieval, despite being relatively immune to disruption, is resource demanding and does not proceed automatically because of consistent costs of DA to distracting task performance. They have suggested that general attentional resources, likely mediated by the FLs, are necessary for placing the cognitive system into a retrieval mode and for voluntary strategic operations that elaborate and augment cues provided during retrieval.

One way of accounting for this mixture of results from studies of DA at retrieval is in the context of a neuropsychological model, which ascribes different memory functions to different brain regions. The component-process model of memory (Moscovitch, 1992; Moscovitch & Umiltà, 1990, 1991) suggests that a key factor determining whether interference is created by DA at retrieval is the extent to which retrieval is dependent on strategic processes mediated by the PFC and on associative, cue-dependent processes mediated by the medial temporal lobe/hippocampus (MTL/H). According to the model, frontally mediated retrieval processes are resource demanding, whereas those mediated by the MTL/H are modular and require fewer general resources for their operations. Performance on some tests of memory relies heavily on processes mediated by the PFC, whereas performance on others does not. On the former types of tests, reliable and substantial interference effects from DA at retrieval can be found. These arguably occur because the concurrent task draws critical resources away from the memory task, thereby hindering performance. Examples of such tasks include recall of categorized lists (Moscovitch, 1994; Park et al., 1989), list discrimination (Dywan & Jacoby, 1990; Jacoby, 1991), and release from proactive inhibition (Moscovitch, 1989, 1994), which are largely disrupted by distracting tasks.

Other memory tests do not rely as heavily on PFC resources but are carried out instead primarily by the MTL/H. For example, free recall, cued recall, or recognition of *unrelated* words is affected little by DA at retrieval (N. D. Anderson et al., 1998; Baddeley et al., 1984; Craik et al., 1996; Naveh-Benjamin et al., 1998; but see Rohrer & Pashler, 2003). Performance on these tests is often disrupted by MTL/H damage but rarely by frontal damage (Milner, Petrides, & Smith, 1985; Moscovitch, 1982; Schacter, 1987). According to the component process model, the memory trace consists of an ensemble of neurons in the neocortex (and elsewhere) that represents the conscious experience that occurred at encoding, which includes the perceptual and semantic content of that experience, all bound together by the MTL/H. In the case of memory for words, the trace likely includes orthographic, phonological, and semantic representations and the context in which the words occurred. During associative retrieval, an internally generated or externally presented cue automatically activates the MTL/H, which acts as a pointer or index to the neocortical neurons representing the content of the trace, and reactivates it, thus minimizing the need for prefrontal involvement. The outcome of the cue-trace interaction, a process called *ecphory*, represents the recovered memory trace (Semon, 1924, cited in Schacter, Eich, & Tulving, 1978; Tulving, 1991).

Some recent studies, however, have shown that retrieval of a list of unrelated words *can* be disrupted by DA, and these new observations need to be accounted for by current models of memory. Fernandes and Moscovitch (2000, 2002, 2003) showed that when free recall of unrelated words is performed concurrently with a word-based distracting task, memory performance is disrupted to a larger degree compared with when the distracting task is digit or picture based. According to the component-process model, a concurrent task at retrieval could potentially impair trace recovery by disrupting either MTL/H function or the neocortical representation itself. The work of Fernandes and Moscovitch suggests that performing a word-based task concurrently with recall of words produces large interference effects by disrupting reactivation of neocortical representations that are part of the memory trace (see also, Moscovitch, Fernandes, & Troyer, 2001).

It is possible, however, to offer alternative accounts for their results. The large memory interference effect could potentially be due to competition for general attentional resources, such as those mediated by the FLs. For example, performing a recall task under dual-task conditions may require additional PFC-mediated resources to coordinate the online processing of dual tasks. In the case of the word-based distracting tasks, retrieval may be disrupted to a relatively greater extent than it is disrupted from digit-based tasks because the similarity in materials makes it more difficult to coordinate the two tasks and overextends a limited pool of general processing resources.

Along the same lines, interference could also occur at the level of input–output channels. That is, processing of incoming words in a word-based distracting task may require a verbal working memory (WM) system, while at the same time, words for the recall task may need the same resources before output. This idea is in line with Baddeley's (1986; 1992) hypothesis that the ability to coordinate concurrent tasks relies on the central executive (CE), whose operation requires resources mediated by PFC, in his working memory model. Taken a step further, coordination of concurrent tasks that require the same slave subsystem may be more difficult than coordination of concurrent tasks that require the verbal and visuospatial subsystem, respectively. These resource-based accounts suggest that retrieval under DA conditions with a word-based distracting task occurs successfully, but it is coordination at *output* that is hampered by the distracting task. The component-process model, on the other hand, suggests retrieval interference occurs during reactivation of the memory traces *prior* to output, and interference is not based on competition for general resources needed for PFC (and CE) function. In this study, we tested the prediction that the large interference effect from word-based distracting tasks is due to competition for general resources required by the FLs.

Our approach was to examine the performance of older adults under DA conditions at retrieval. The reason for testing older adults is that aging is often presumed to be associated with deficits in memory stemming from a reduction in general processing resources that are critical for numerous cognitive operations (Craik, 1983; Craik & Byrd, 1982; Rabinowitz, Craik, & Ackerman, 1982). These resources have been conceptualized in many ways, but regardless of how these are conceptualized, cognitive aging theories converge on the idea that changes in brain function, particularly in the FLs, underlie the reduction in resources (e.g., Baddeley & Wilson, 1988; Fuster, 1997; Knight, Grabowecky, & Scabini 1995; Luria, 1966; Shallice & Burgess, 1991), although other brain regions, including the MTL/H, also deteriorate with age (Moscovitch & Winocur, 1992).

There is also evidence suggesting that not all cognitive functions are similarly affected by aging and that the rate of decline may differ depending on the given function. Individuals may differ with respect to which functions are most affected (Albert, 1988; Welford, 1993). Glisky, Polster, and Routhieaux (1995) took advantage of this variability to differentiate among groups of older adults on their level of functioning. Using neuropsychological testing, they assessed the level of frontal and temporal lobe function for each individual, relative to the group as a whole. They conducted a factor analysis on a selection of neuropsychological tests thought to depend on frontal and temporal lobe function. From this, they were able to calculate two *z* scores for each participant, one that represented a composite of FL function and one that represented a statistically independent MTL function. They were thus able to classify each older adult in their pool as high or low on frontal and temporal lobe function (see Glisky et al., 1995; Glisky, Rubin, & Davidson, 2001, for details).

In the present experiment, we considered the performance of older adults in Glisky et al.'s (1995, 2001) population to examine how each region might be related to memory under DA conditions during retrieval. A general resource account for large effects of DA at retrieval predicts larger interference effects in individuals with compromised frontal function, as they have fewer resources available to coordinate the dual tasks. The component-process model, however, places the locus of interference outside of the FLs, in posterior neocortex regions that form the content of the memory; thus, it predicts similar magnitudes of interference regardless of level of frontal functioning. The component-process model also proposes that the MTL/H is a modular system, and thus older adults' level of MTL function should not alter the magnitude or pattern of interference effects under DA conditions. Because the MTL is important for episodic memory, during both encoding and retrieval, those with lower levels of functioning are likely to recall fewer words overall than those with higher levels of functioning; both a general resource and the component-process model make this prediction.

In addition to the effects of DA on memory, we examine how the levels of FL and MTL function affect performance on the distracting tasks. Several researchers have suggested that this measure reflects the resource-demanding aspect of retrieval (N. D. Anderson et al., 1998; Craik et al., 1996; Fernandes & Moscovitch, 2000, 2002, 2003; Naveh-Benjamin et al., 1998), mediated by the FL. If this is true, then those with lower FL function should show higher distracting-task costs.

Finally, research has shown that aging is associated with a decline in episodic memory (Craik & Jennings, 1992; Salthouse, 1991), which may stem from difficulties with encoding and/or elaboration at encoding (Craik, 1982, 1983, 1986). For this reason, we allowed participants to listen to study lists twice at encoding. If the free recall under full attention (FA) was very low, missing just one word under DA conditions would result in a significant drop in performance, making comparisons between conditions and across groups problematic. What is more, previous work (Fernandes & Moscovitch, 2003) showed that the magnitude and pattern of interference from DA conditions at retrieval did not vary depending on whether word lists were studied once or twice at encoding.

Method

Participants

Seniors were selected from a larger pool of healthy, community-dwelling adults over the age of 65 who had undergone extensive neuropsychological testing at the University of Arizona. Each participant in the pool had been assigned two scores, one representing relative performance on a group of tests associated with FL function and the other representing relative performance on a group of tests believed to assess MTL function. The tests comprising the FL factor were the following: number of categories achieved on the modified Wisconsin Card Sorting Test (Hart, Kwentus, Wade, & Taylor, 1988), the total number of words generated during a letter fluency (*F*, *A*, and *S*) test (Spreen & Benton, 1977), Mental Arithmetic from the Wechsler Adult Intelligence Scale—Revised (Wechsler, 1981), Mental Control from the Wechsler Memory Scale—Revised (WMS–R; Wechsler, 1987), and Backward Digit Span from the WMS–R. The tests comprising the MTL factor were Logical Memory I, Verbal Paired Associate I, and Visual Paired Associate II (all from the WMS–R) and the Long-Delay Cued Recall measure from the California Verbal Learning Test (Delis, Kramer, Kaplan, & Ober, 1987). These tests were grouped according to the results of a factor analysis of data from a group of 100 older adults (reported in Glisky et al., 2001) in which variance attributable to age was removed from test scores prior to the factor analysis.

For participants in the present study, composite scores represent average *Z* scores based on the 100-member normative group for those tests loading on each factor. We tested 24 older adults in total: 6 were chosen with high FL and high MTL (HH group), 6 with low FL and low MTL (LL group), 6 with low FL and high MTL (LH group), and 6 with high FL and low MTL (HL group) function. They received monetary compensation for their participation. Characteristics of each group are presented in Table 1.

We examined whether the groups differed with respect to age, years of education, Mini-Mental State Exam (MMSE; Folstein, Folstein, & McHugh, 1975) score, and full-scale IQ using a 2×2 analysis of variance (ANOVA; FL classification and MTL classification are used as between-subjects variables) for each variable. There were no main effects of age or education, and the FL $\times$ MTL interactions were nonsignificant. There was an effect of FL classification and MTL classification on MMSE score, $F(1, 20) = 4.90$, $p < .05$, and $F(1, 20) = 9.61$, $p < .01$, respectively, with lower function groups scoring less than the high function ones, but the interaction of FL $\times$ MTL was nonsignificant. Mean MMSE scores in each group were greater than 26/30, which indicates normal functioning. There was a main

Table 1
Characteristics of Older Adults as a Function of Neuropsychological Group

	High FL function				Low FL function			
	High MTL function		Low MTL function		High MTL function		Low MTL function	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age (years)	71.7	3.6	73.0	6.0	71.3	3.4	73.2	3.6
Education (years)	15.7	2.7	16.9	1.8	14.5	3.2	14.3	2.1
MMSE	29.8	0.4	29.0	1.1	29.3	0.8	27.9	1.2
Full-scale IQ	130.8	10.9	115.8	12.8	113.0	13.5	108.7	9.4
WCST categories	6.0	0.0	5.8	0.4	2.8	1.5	4.2	1.2
Letter fluency (*F*, *A*, and *S* total)	50.7	4.2	51.0	3.4	33.5	6.5	33.5	5.9
WAIS–R								
Mental Arithmetic	15.5	2.5	15.0	3.3	11.83	3.4	10.8	3.1
WMS–R								
Mental Control	5.8	0.4	5.7	0.8	5.3	0.8	4.8	1.3
Backward Digit Span	8.8	2.3	8.2	1.0	7.0	1.7	5.2	0.8
Logical Memory I	30.7	6.3	18.5	3.2	27.8	5.8	21.8	7.0
Verbal Verbal PA I	21.7	1.5	18.0	4.1	21.0	1.6	18.4	4.2
Visual PA II	5.8	0.4	5.5	0.8	6.0	0.0	4.7	0.8
CVLT								
Long Delay Cued Recall	13.7	0.8	9.5	3.3	13.8	1.5	10.0	1.8
Composite score								
FL[a]	0.7	0.4	0.7	0.4	−0.5	0.4	−0.7	0.4
MTL[a]	0.7	0.4	−0.4	0.4	0.5	0.3	−0.4	0.3

Note. FL = frontal lobe; MTL = medial temporal lobe; MMSE = Mini-Mental State Exam; WCST = Wisconsin Card Sorting Test; WAIS–R = Wechsler Adult Intelligence Scale—Revised; WMS–R = Wechsler Memory Scale—Revised; PA = paired associate; CVLT = California Verbal Learning Test.
[a] *Z* scores (see *Method* section).

effect of FL classification on full-scale IQ, $F(1, 20) = 6.79$, $p < .05$; the mean for the high-functioning group was greater ($M = 123.33$) than that for the low-functioning group ($M = 110.83$). The main effect of MTL classification on IQ was nonsignificant, as was the FL × MTL interaction.

Overview of Experiment

In each of three separate conditions, participants were asked to try to commit an auditorily presented list of words to memory and subsequently to recall those words freely. The study word lists were each heard twice at encoding. Prior to retrieval, participants began a distracting task (either animacy decisions about words, or odd-digit decisions about two-digit numbers) presented visually on a computer screen. In each of the two DA conditions, participants continued to perform one of the distracting tasks while simultaneously trying to recall out loud the studied word list. Participants also performed a baseline (FA) condition task, in which the distracting task ended prior to free recall.

Materials

All word stimuli were of medium to high frequency, chosen from Francis and Kucera (1982). Word frequencies ranged from 20 to 100 occurrences per 1,000,000.

Recall Task

Four word lists were created by randomly choosing 16 words for each list from a pool of 64 unrelated common nouns. One list was used for the practice block, and the other three for the experimental blocks. Words were recorded in a soundproof booth onto an audio file by a Macintosh computer using the Sound Designer II program (Avid Software, Palo Alto, CA). Each list was created with 3 s of silence inserted between words. The lists were then recorded onto an audiotape and presented by a cassette player.

Distracting Tasks

For the animacy task, three 50-item word lists, consisting of words representing animals (e.g., *mouse*) and man-made objects (e.g., *radio*), were created from a pool of 170 words. One list was used for practice, one for a single-task measure, and the third for the DA condition with recall. A shorter, 20-item word list was also created and used as the filler task in the FA condition prior to recall (see *Procedure*). Each list was created such that half of the words represented animals and half man-made objects.

For the odd-digit task, the same number of 50-item lists was created. Stimuli for this task consisted of two-digit numbers chosen from a table of random numbers (Kirk, 1995). Each list was created such that half the numbers were odd and the other half even.

Procedure

Participants were tested individually and completed the experiment in approximately 1.5 hr. During study for each condition, participants heard a tape-recorded woman's voice reading a list of 16 words at a rate of approximately 1 word every 4 s, and they were asked to try to commit the words to memory for a later recall test. The study list was presented twice during encoding; There was a 4–5-s delay between the first and second presentation. The encoding phase was followed by an arithmetic task in which participants counted backward by 3s from a number heard at the end of the word list for 15 s; this was done to eliminate recency (as in Craik et al., 1996).

For the distracting tasks, the words or numbers were presented visually on a computer screen at a rate of one item every 2 s. For the animacy task, participants indicated whether the word represented a man-made object and, for the odd-digit task, whether the number was odd by pressing a key with the dominant writing hand. Although we recorded manual response times in all of our experiments, we did not emphasize to participants the importance of responding quickly on the distracting tasks when performed singly and under DA conditions with retrieval.

Participants were given a practice block for the memory task, followed by practice for the animacy, and then the odd-digit distracting task prior to performing all of the experimental conditions. Following the practice blocks, single-task performance for either the animacy or odd-digit distracting task was measured. Single-task performance for the remaining distracting task was measured at the end of the final experimental condition. The order of the single tasks was counterbalanced across participants.

Following the first single-task measure, the three experimental condition tasks (FA and two DA conditions) were administered (six different orders of presentation were used). Following the study phase (and arithmetic task) in each experimental condition, and prior to recall, participants performed one of the distracting tasks alone for 40 s, until the computer emitted a low-pitched tone. For the animacy task, half of the items represented man-made objects, and for the odd-digit task half were odd numbers (the maximum number of hits for each task was 10). The tone signaled that recall of taped words should begin. For the DA conditions, this was done so that participants would be engaged in the distracting task prior to beginning recall. In the FA condition, participants performed the animacy task as a filler (using the 20-word list), which ended once the computer signaled that recall of the taped words should begin. In this way, the time lag between study and test, as well as the need to perform another task before recall, was the same in the DA and FA conditions.

In the two DA conditions, the animacy or odd-digit task continued on the computer while participants simultaneously tried to recall studied words. The distracting and free-recall tasks were performed simultaneously for 60 s (half of the distracting task items were man-made words or odd numbers in the animacy and odd-digit conditions, respectively, and the maximum number of hits was 15 for each condition). Participants were told to divide their efforts equally between the two tasks. The importance of placing 50% of their effort on the recall task and 50% on the distracting task was emphasized. After recall in the DA conditions, the experimenter asked participants whether they recalled any additional words from the study list, now that they did not have to do two things simultaneously; they were given as much time as they wanted for this task, but rarely took more than a minute to give a response, if any. Participants' recall responses were tape-recorded. Participants were given a short break before beginning each experimental condition.

Table 2
Number of Words Recalled and Percentage Change From Single- to Dual-Task Condition for Each Measure in Each Group

	FL function					
	High		Low		Overall	
MTL function	*M*	*SD*	*M*	*SD*	*M*	*SD*
Words recalled						
High						
FA	8.5	1.8	8.0	3.3	8.3	2.6
DA digits	6.8	2.7	7.0	3.2	6.9	2.8
DA animacy	4.8	2.0	4.5	2.3	4.7	2.1
Low						
FA	6.8	2.6	5.2	2.5	6.0	2.6
DA digits	5.8	3.9	5.0	1.8	5.4	2.9
DA animacy	3.8	2.3	3.0	1.1	3.4	1.8
Overall						
FA	7.7	2.3	6.6	3.2		
DA digits	6.3	3.3	6.0	2.7		
DA animacy	4.3	2.1	3.8	1.9		
Percentage decline in recall						
High						
DA digits	18.4	35.6	13.4	10.8	15.9	25.2
DA animacy	39.3	29.8	40.0	26.6	39.7	26.9
Low						
DA digits	20.2	38.5	−14.1	52.0	2.7	47.3
DA animacy	44.8	23.5	32.1	40.6	38.5	32.3
Overall						
DA digits	19.3	35.4	−0.6	38.7		
DA animacy	42.1	25.7	36.1	32.3		

Note. FL = frontal lobe; MTL = medial temporal lobe; FA = full attention; DA = divided attention.

Results

Memory Task

We conducted separate analyses using the number of words recalled and percentage decline in memory as dependent variables. There were no significant main effects or interactions with Order factors (Order of Experimental Conditions and Order of Single-Task Measure for each distracting task) on number of words recalled or on percentage decline in recall.

Number of words recalled. The animacy distracting task interfered substantially with free-recall performance, whereas the odd-digit task had a smaller effect on memory. Importantly, this pattern of results was similar in all groups, indicating that level of FL and MTL dysfunction does not influence memory interference from DA. The means for each condition are presented in Table 2. A 2 × 2 × 3 ANOVA was carried out using FL classification and MTL classification as between-subjects variables ($n = 12$ for each classification) and experimental condition (FA, DA animacy, DA odd-digit) as a within-subject variable. There was a significant effect of experimental condition, $F(2, 40) = 21.52$, $MSE = 2.78$, $p < .001$, $\eta^2 = .52$. More words were recalled in the FA condition compared with the DA animacy and DA odd-digit condition, $F(1, 20) = 35.74$, $MSE = 6.38$, $p < .001$, $\eta^2 = .64$, and $F(1, 20) = 5.79$, $MSE = 3.81$, $p < .05$, $\eta^2 = .22$, respectively. There were significantly fewer words recalled in the animacy compared with the odd-digit DA condition, $F(1, 20) = 16.74$, $MSE = 6.48$, $p < .001$, $\eta^2 = .46$. There was a trend for those with poorer MTL function to recall fewer words than those with higher MTL functioning, $F(1, 20) = 3.46$, $p = .08$, $\eta^2 = .19$. All other main effects and interactions were nonsignificant (Fs < 1.00; see supplementary material, which is available on the Web at http://dx.doi.org/10.1037/0894-4105.18.3.514.supp, for ANOVA source tables listing all nonsignificant results).

Percentage decline in memory under DA conditions. In the following analyses, we examined interference effects from DA using the percentage decline in words recalled (relative to each participant's own FA level of recall) as the dependent variable. This was done for each participant by subtracting the number of words recalled in each of their DA conditions from the number recalled under FA and then dividing by the number of words recalled under FA. Again, the level of FL and MTL function did not modulate the magnitude of interference from DA, and memory interference effects were consistently larger when attention was divided at retrieval using the animacy compared with the odd-digit task.

A 2 × 2 × 2 ANOVA was carried out using FL classification and MTL classification as between-subjects variables and DA condition (animacy, odd-digit) as a within-subject variable. There was a significant effect of DA condition, $F(1, 20) = 20.05$, $MSE = 0.053$, $p < .001$, $\eta^2 = .50$, with a greater decline in memory in the animacy than the odd-digit DA condition. All other main effects and interactions were nonsignificant (Fs < 1.00).

Other measures of memory. Following each DA condition, participants were given the chance to recall words from the study list under FA. The number of additional words recalled following each DA condition, for each group, is presented in Table 3. Analyses were conducted using FL and MTL classification ($n = 12$ for each) as between-subjects variables and DA condition as a within-subject variable. The main effect of DA condition was significant, $F(1, 20) = 4.56$, $MSE = 1.32$, $p < .05$, $\eta^2 = .19$, with more words recalled following the DA animacy than were recalled in the DA odd-digit condition; both two-way and three-way interactions of DA condition, with the FL and MTL factors, were nonsignificant, $F = 1.91$ and $F = 0.39$, ps $> .05$, respectively.

There was no effect of MTL grouping on number of additional words recalled ($F < 1.00$), but participants with low FL function recalled more additional words than did those with high FL function, $F(1, 20) = 4.59$, $MSE = 1.64$, $p < .05$, $\eta^2 = .19$. The interaction of FL × MTL classification was also significant $F(1, 20) = 10.70$, $MSE = 1.64$, $p < .01$, $\eta^2 = .35$. For those with low MTL functioning, their level of FL function did not change the number of additional words recalled (it remained low), but for those with high MTL function, their level of FL function mattered (see Figure 1). Few additional words were recalled for those with high MTL combined with high FL function, whereas more were recalled for those with high MTL combined with low FL function. Presumably, those with high MTL and FL function can recall all words available to them, even under DA conditions, whereas those with low FL function have difficulty recovering all available words from memory under the DA conditions but can recover additional items once the dual-task manipulation ends.

Table 3
Additional Words Recalled Following Each Divided Attention Condition for Each Group

	FL function					
	High		Low		Overall	
MTL function	*M*	*SD*	*M*	*SD*	*M*	*SD*
High						
DA digits	0.7	0.8	2.2	1.0	1.4	1.2
DA animacy	0.7	1.2	3.2	1.0	1.9	1.7
Low						
DA digits	1.5	1.2	0.7	0.8	1.1	1.1
DA animacy	2.0	1.4	2.0	1.9	2.0	1.6
Overall						
DA digits	1.1	1.1	1.4	1.2		
DA animacy	1.3	1.4	2.6	1.6		

Note. FL = frontal lobe; MTL = medial temporal lobe; FA = full attention; DA = divided attention.

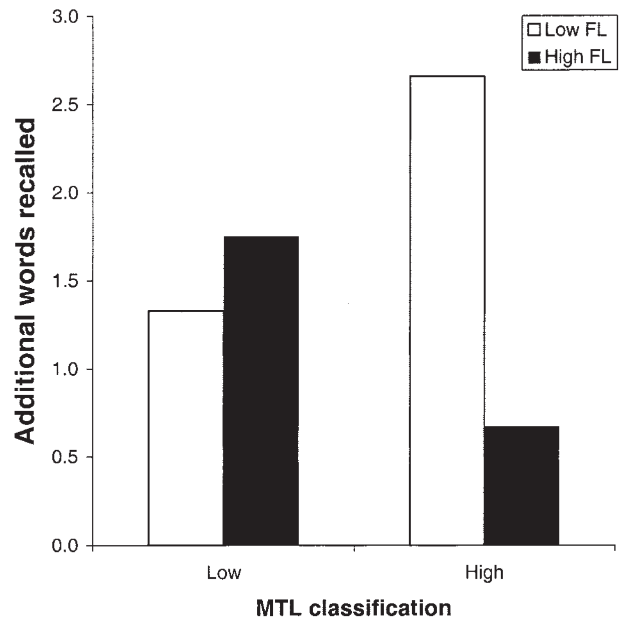

Figure 1. Additional words recalled following divided attention conditions for older adults with high versus low frontal lobe (FL) function as a function of level of medial temporal lobe function (MTL).

To determine whether the effects of DA on memory were *persistent* (even when given additional time to recall words following the DA conditions), we conducted an ANOVA using the *total* number of words recalled in each condition as the dependent variable. A 2 × 2 × 3 ANOVA was carried out using FL classification and MTL classification as between-subjects variables and experimental condition (FA, DA animacy, DA odd-digit) as a within-subject variable. The significant effect of experimental condition was maintained even when total words recalled was the dependent measure, $F(2, 40) = 5.51$, $MSE = 2.44$, $p < .01$, $\eta^2 = .35$. The total number of words recalled was lower in the DA animacy ($M = 6.00$) than in the FA condition ($M = 7.13$), $F(1, 20) = 6.07$, $MSE = 5.01$, $p < .05$, $\eta^2 = .35$, though there was no difference between the DA odd-digit ($M = 7.42$) and FA conditions, $F < 1.00$. Moreover, there were significantly fewer words recalled, in total, in the animacy condition compared with the odd-digit DA condition, $F(1, 20) = 7.28$, $MSE = 5.01$, $p < .05$, $\eta^2 = .27$. There was a trend for those with low MTL function to recall fewer words overall ($M = 17.92$) than those with higher MTL functioning ($M = 23.17$), $F(1, 20) = 3.70$, $p = .07$, $\eta^2 = .16$.

Distracting Tasks

Analyses were conducted using accuracy rate (hit rate − false alarm rate) as the dependent variable (see Table 4 for means). There were no significant main effects or interactions with the order factors.

Accuracy rate. Those with low FL function showed a trend to perform more poorly on the distracting tasks compared with those with high FL function. Accuracy rates were calculated as number of hits/15 − number of false alarms/15 for the animacy and odd-digit distracting tasks in the FA and DA conditions. Data were

Table 4
Accuracy Rates on Distracting Tasks and Percentage Change From Single- to Dual-Task Condition for Each Measure in Each Group

	FL function					
	High		Low		Overall	
MTL function	*M*	*SD*	*M*	*SD*	*M*	*SD*
Accuracy rate						
High						
Baseline digits	0.93	0.07	0.90	0.06	0.92	0.06
Baseline animacy	0.91	0.04	0.90	0.06	0.91	0.05
DA digits	0.83	0.09	0.83	0.07	0.83	0.08
DA animacy	0.76	0.16	0.72	0.11	0.74	0.13
Low						
Baseline digits	0.89	0.04	0.87	0.10	0.88	0.07
Baseline animacy	0.90	0.06	0.87	0.07	0.88	0.06
DA digits	0.83	0.09	0.71	0.16	0.77	0.14
DA animacy	0.77	0.12	0.71	0.18	0.74	0.14
Overall						
Baseline digits	0.91	0.05	0.88	0.08		
Baseline animacy	0.91	0.05	0.88	0.06		
DA digits	0.83	0.09	0.77	0.13		
DA animacy	0.77	0.13	0.72	0.14		
Percentage decline in accuracy rate						
High						
DA digits	10.90	4.70	7.80	9.60	8.98	7.51
DA animacy	16.70	19.50	19.40	14.10	18.07	16.30
Low						
DA digits	5.80	11.50	17.00	20.40	11.41	16.82
DA animacy	13.80	10.40	18.20	19.40	15.99	15.04
Overall						
DA digits	8.35	8.83	12.04	16.04		
DA animacy	15.25	14.99	18.81	16.20		

Note. FL = frontal lobe; MTL = medial temporal lobe; FA = full attention; DA = divided attention.

analyzed in a 2 (task) × 2 (attention) × 2 (FL classification) × 2 (MTL classification) ANOVA, with the first two variables within-subject and the last two between-subjects manipulations. The effect of FL classification approached significance, $F(1, 20) = 3.23$, $MSE = 0.01$, $p = .08$, $\eta^2 = .14$. There was a main effect of attention, $F(1, 20) = 52.24$, $MSE = 0.01$, $p < .001$, $\eta^2 = .72$, with poorer performance under DA than single-task conditions. The main effect of task and MTL classification was nonsignificant, as were all two- and three-way interactions and the four-way interaction.

The correlation between accuracy rate on each distracting task under the DA conditions and memory interference for that condition was nonsignificant across all participants. Thus, trade-offs between the memory and distracting tasks do not appear to be a factor influencing performance levels.

Reaction time (RT). The mean RT for participants responding to target items for each distracting task in the single-task and DA conditions is noted in Table 5 for each group. There were no significant group differences across conditions. Data were analyzed in a 2 (task) × 2 (attention) × 2 (FL classification) × 2 (MTL classification) ANOVA, with the first two variables being within-subject and the last two between-subjects manipulations. There was a main effect of attention, $F(1, 20) = 166.55$, $MSE = 4{,}295.11$, $p < .001$, $\eta^2 = .89$, with slower RTs under DA conditions, and a main effect of task, $F(1, 20) = 77.94$, $MSE = 8{,}368.27$, $p < .001$, $\eta^2 = .80$. All interactions with these factors were nonsignificant. Planned comparisons showed that the RTs for the animacy task were longer than for the odd-digit task under single-task conditions, $t(23) = 7.57$, as well as under DA conditions, $t(23) = 5.64$. The main effects of FL and MTL classification were nonsignificant, as were all two- and three-way interactions and the 4-way interaction with the within-subjects variables, Fs < 1.00.

The correlation between RT for each distracting task under the DA conditions and memory interference was nonsignificant. Thus, trade-offs in performance between the dual tasks are not apparent.

Discussion

We classified older adults on the basis of neuropsychological test scores as having either high or low FL and MTL function to evaluate the contribution of these regions to interference effects from DA at retrieval. According to the component-process model,

Table 5
Reaction Time (in Milliseconds) on Distracting Tasks and Percentage Increase From Single- to Dual-Task Condition for Each Measure in Each Group

	FL function					
	High		Low		Overall	
MTL function	*M*	*SD*	*M*	*SD*	*M*	*SD*
Reaction time						
High						
Baseline digits	694	98	647	48	671	77
Baseline animacy	863	84	813	112	838	98
DA digits	931	53	848	104	889	90
DA animacy	1014	96	984	83	999	87
Low						
Baseline digits	629	121	684	80	657	102
Baseline animacy	801	67	860	165	830	124
DA digits	751	141	838	166	794	154
DA animacy	1004	98	1003	109	1003	99
Overall						
Baseline digits	662	110	666	66		
Baseline animacy	832	79	836	137		
DA digits	841	138	843	132		
DA animacy	1009	92	993	93		
Percentage increase in reaction time						
High						
DA digits	25	13	22	14	24	13
DA animacy	15	4	17	9	16	7
Low						
DA digits	15	11	16	15	16	12
DA animacy	20	5	14	14	17	11
Overall						
DA digits	20	12	19	14		
DA animacy	17	5	16	11		

Note. FL = frontal lobe; MTL = medial temporal lobe; FA = full attention; DA = divided attention.

the effects of DA on memory arise from competition for representations, possibly in posterior neocortex regions. Thus, whether a participant has a high or low level of FL or MTL function should have minimal influence on the extent of interference. However, according to a general resource model, the level of FL function should influence susceptibility to interference. Similarly, a WM account of interference effects from DA at retrieval, as described previously, suggests that the availability of resources mediated by the FL underlie large interference effects from DA at retrieval.

Our study showed that DA using the animacy task produced very large levels of interference, ranging from a 32% to a 45% drop in performance from FA conditions across groups. Smaller interference effects were observed when the odd-digit task was performed with recall (range: –14%–20%). These data support the claim that effects from DA at retrieval are modulated by the type of material in the distracting task (Fernandes & Moscovitch, 2000, 2002, 2003), though we acknowledge there may be other loci contributing to interference at retrieval, as a significant reduction in words recalled was found in the odd-digit DA condition, at least for some groups (see also, Rohrer & Pashler, 2003).

These results argue against a resource account of DA effects at retrieval. If competition for resources could account for the large effects of DA from word-based distracting tasks, memory interference in participants with poor FL function should have been amplified relative to those with high FL function, because the former have to compensate for an even greater reduction in available resources. Our results are in line with other work (N. D. Anderson et al., 1998; Fernandes & Moscovitch, 2002; Nyberg, Nilsson, Olofsson, & Bäckman, 1997) in which the reduction in available processing resources believed to characterize aging, and attributed to deterioration of the FL, did not alter the pattern or magnitude of interference on memory from that observed in younger adults.

In addition, we observed persistent effects of DA when the distracting task consisted of words. That is, once disrupted, very few additional words from the study list could be recovered, even when the DA condition ended, with one notable exception. If competition for a verbal WM system or CE at output was the locus of interference effects, memory for words from the study list was expected to recover once DA was removed. Though some recovery occurred, it did not eliminate the interference effect, except in the low FL group, which presumably had the worst WM. Furthermore, analyses showed that the number of words recalled for the DA animacy condition remained significantly lower than that in the FA condition, even when additional words recalled following the DA condition were included in the dependent measure. On the other hand, the difference in recall levels between the FA and DA odd-digit conditions was no longer significant once additional words recalled were added to the score. Thus, interference in the DA animacy condition is persistent, whereas the effect from the DA odd-digit condition is transient. This result suggests that the animacy task is disrupting not simply the output of study list words but also the content of the memories themselves. The odd-digit task, however, may compete for resources in WM. This latter conclusion is consistent with our finding that the low FL/high MTL group was the only one to recall significantly more items when given an additional opportunity. This is the one group whose WM presumably is poor, yet its members had sufficiently good long-term memory to retain the material. Once the effects of DA are removed, they can benefit from recalling the remaining items they retained.

It is also worth noting that despite differences in full-scale IQ in the high and low FL groups, the magnitude of memory interference remained unchanged. If we consider higher levels of intelligence as indicative of greater cognitive reserve (Stern, 2002), this too is unrelated to the magnitude of memory interference. This finding is in line with our claim that availability and flexibility of general resources are unrelated to memory interference from DA at retrieval.

Looking at performance on the distracting tasks, one might suggest that the large and persistent interference effects on memory arise because of the level of difficulty of the animacy compared with the odd-digit task. Indeed, participants were slower to make responses for the animacy task, but there were no differences with respect to accuracy. Moreover, in a recent study (see Fernandes & Moscovitch, 2003), we directly compared the level of difficulty of the animacy to the odd-digit task and found no indication that this factor played a role in modulating interference effects on recall.

As expected, the level of MTL function influenced the number of words recalled: Those with low MTL function showed a trend to recall fewer words compared with those with high levels of function. The pattern and size of interference, however, did not vary with level of MTL function. As Figure 2 shows, the only striking difference across groups is that those with low MTL function recalled fewer words in all conditions; otherwise, the drop in performance from FA to each of the DA conditions is equivalent across groups.

The current results, coupled with our other work (Fernandes & Moscovitch, 2000, 2002, 2003), suggest that the locus of large interference from DA at retrieval is at the level of "representations" that form the content of the memory trace. These likely include orthographic, phonological, lexical, and semantic representations; competition from a word-based distracting task can

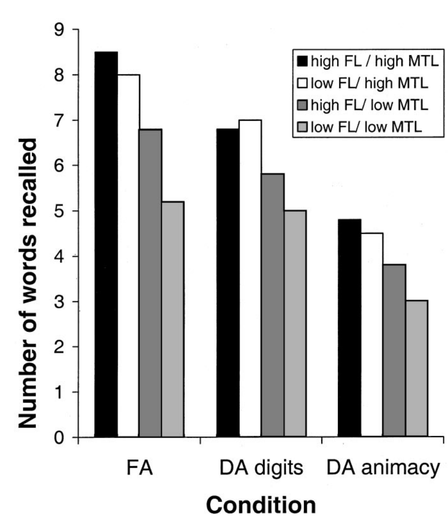

Figure 2. Free recall in each condition for each group. MTL = medial temporal lobe; FL = frontal lobe; FA = full attention; DA = divided attention.

occur at any or all of these levels of representation. Notably, our recent work has shown that the primary locus for competition with retrieval of words is greatest for phonological or orthographic representations, though some competition at other levels was also found (Fernandes & Moscovitch, 2002; Fernandes, Priselac, & Moscovitch, 2004).

In this study, we also considered whether low levels of FL functioning lead to higher distracting task costs. Several researchers have suggested that the resource-demanding aspect of retrieval is likely to be in the establishment and maintenance of retrieval mode, as well as in monitoring output (N. D. Anderson et al., 1998; Craik et al., 1996; Fernandes & Moscovitch, 2000, 2002, 2003; Griffith, 1976; Johnston et al., 1970, 1972; Naveh-Benjamin et al., 1998; Trumbo & Milone, 1971), and they have also suggested that these processes are mediated by the FL. Insofar as the memory task makes use of these processes, these resource demands should be reflected in costs to distracting task performance. In support of this claim, we found a trend for those with low FL function to have larger distracting task costs under DA conditions, suggesting these effects are related to the integrity of the FL (see Figure 3). It should also be noted that we found large costs to performance under DA conditions in all groups, suggesting that retrieval *is* resource demanding. In addition, the costs to the distracting task did not differ for the animacy and odd-digit task. Thus, unlike the effects of different distracting tasks on memory, which are material specific, effects on the distracting task likely reflect a more general resource requirement, mediated by the FL.

It should be mentioned, however, that the FLs are implicated in many processes. Even a composite measure of FL function, such as the one used in our study, does not capture all aspects of FL function but only measures a subset of them. It is possible, therefore, that FL functions not captured by our measure mediate performance on DA tasks. We think this interpretation is unlikely for two reasons. First, we observed a trend for those with low FL function to show higher distracting task costs but with no noticeable effect on memory costs. Second, FL function is related to a person's ability to recover additional material once the DA condition was completed. Thus, our measures of FL function are sensitive to various aspects of resource allocation and memory

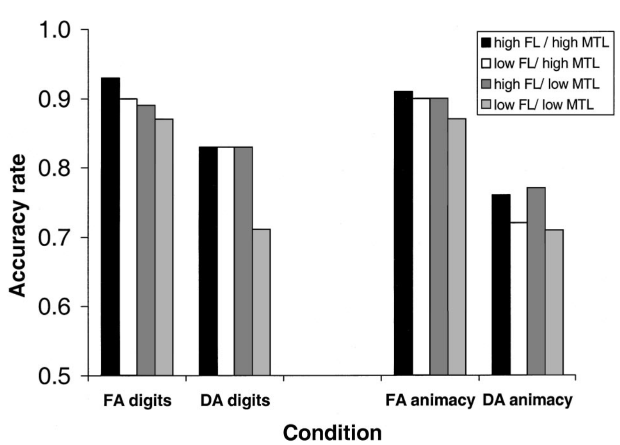

Figure 3. Accuracy rate for each distracting task in single and divided attention conditions for each group. MTL = medial temporal lobe; FL = frontal lobe; FA = full attention; DA = divided attention.

retrieval but not to those contributing to word recall under DA. Consistent with the component-process model, that aspect is less dependent on the FL.

The absence of a large and persistent interference effect on memory from digit-based distracting tasks suggests that digits can be represented or processed independently from words or word forms. Consistent with this claim, Allison, McCarthy, Nobre, Puce, and Belger (1994), using electrophysiological recordings, showed a negative potential, N200, in discrete regions of the fusiform and inferior temporal gyri that were in different locations for face, letter-string, and number stimuli. This led the authors to conclude that there are different "modules" for the processing of numbers, in addition to, as previously suggested, separate processing streams for faces and words (Farah, 1990; Farah, Wilson, Drain, & Tanaka, 1998). Although the distracting tasks used in the present study likely involved additional brain regions (left lateral temporal, parietal, precuneus) for representation of words with semantic and phonological content and of numbers requiring classification, it is noteworthy that a distinction between these two types of materials can be made at a basic level of visual representation.

An interesting line of inquiry stemming from our work would be to consider whether young children, who perhaps have not yet developed distinct letter and number modules, show large interference effects under DA at retrieval from *both* digit- and word-based distracting tasks rather than from word-based tasks alone, as demonstrated in adults who have developed separate modules to represent these materials. Along similar lines, one could evaluate whether expertise in viewing numbers influences the magnitude of memory interference. That is, one could compare the levels of interference in United States mail sorters, who have greater experience viewing numbers and presumably have had a chance to develop a very specialized number representational system that is distinct from letters, to those observed in Canadian mail sorters, who see letters and numbers together more frequently and have less-distinct letter and number modules (as in Polk & Farah, 1995).

Although our current results are in line with the component-process model, it is worth considering other work in which memory retrieval is disrupted. M. C. Anderson, Bjork, and Bjork (1994) asked participants to practice retrieving half of the items from each of several categories. In an ensuing retrieval session, in which all items from the categories were to be recalled, they found that recall of nonpracticed items was inhibited relative to a control condition. The authors explained this effect in terms of inhibition or suppression of unpracticed items during the retrieval practice session that persists to the subsequent retrieval session. This phenomenon is referred to in the literature as the *part-list cueing effect,* for which the act of retrieval inhibits recall of information that is associated with the successfully retrieved target information (Roediger, 1973; Slamecka, 1968). An interesting line of inquiry would be to investigate whether the locus of retrieval interference under DA is the same as that in part-list cueing. If it is, even greater interference effects in a DA study should be observed when words in a distracting task are related versus unrelated to words from the study list, as retrieval may be inhibited more in the case of highly associated words. This study would also answer questions as to whether the locus of interference also occurs at a semantic level (see Fernandes & Moscovitch, 2002).

Our results suggest that deterioration in FL or MTL function in normal older adults does not amplify susceptibility to memory disruption under DA conditions if memory retrieval is nonstrategic. Furthermore, although poor MTL function does lead to poorer memory, it does not lead to greater susceptibility to distraction. It is primarily when the memory task shares the same representational system as the distracting task that large effects on memory are seen. Our results also suggest that retrieval of unrelated words is not an obligatory process in the sense that it is immune to interference. Performing a word-based task concurrently with recall of words interferes with recovery and/or reactivation of the trace. Our results are inconsistent with the notion that effects of DA at retrieval are due to a reduction in general processing resources, attentional capacity, output interference, or competition for memory structures in the temporal lobe. In addition, it has been suggested that establishing and maintaining retrieval mode and monitoring output are resource-demanding aspects of retrieval mediated by the FL. Our results support this claim. We found costs to distracting task performance under DA conditions that were similar in magnitude regardless of whether the material used to divide attention was word-based or numerical, and these were elevated in those with poor FL function, suggesting this region plays a role in allocating or coordinating resources for such functions. Additional studies using functional neuroimaging or patients with focal brain lesions may provide converging evidence regarding the locus of effects of DA on memory retrieval.

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Received August 12, 2002
Revision received August 14, 2003
Accepted August 14, 2003 ■