MEMORY, 2009, 17 (2), 158–168

Psychology Press
Taylor & Francis Group

Ageing, remembering, and executive function

David Clarys, Aurelia Bugaiska, Géraldine Tapia, and Alexia Baudouin
Université François-Rabelais de Tours, France

This study was designed to investigate the relationship between executive functions and the age-related decline in episodic memory through the states-of-awareness approach. Following the presentation of a word list, a group of younger adults and a group of older adults undertook a recognition test in which they classified their responses according to the Remember-Know-Guess procedure (Gardiner & Richardson-Klavehn, 2000). In order to operationalise the executive function hypothesis, we investigated three specific executive functions (updating, shifting, and inhibition of a prepotent response) described in Miyake et al.'s (2000) theoretical model, and a complex executive task. The results revealed that fewer "R" responses were made during the recognition test by the older than the younger group, whereas there was no difference between the groups in the number of "K" responses. In addition, correlations indicated that remembering depended on executive function measures, whereas knowing did not. The hierarchical regression analyses showed that controlling for executive function, and particularly for the 2-back test, largely removed the age-related variance in remembering. These findings support the notion that executive dysfunction, and specifically updating decline, plays a central role in age-related memory loss.

Keywords: Ageing; Memory; States of Awareness; Executive Function.

Tulving (1983, 1985) suggested that a defining property of episodic and semantic memory systems is the phenomenological subjective experience that accompanies retrieval from them, and proposed a distinction between two kinds of consciousness: autonoetic and noetic. He showed that participants could readily understand the distinction between the two kinds of awareness, and could report them using Remember and Know responses. He used the term "remembering" to refer to the expression of autonoetic consciousness, which corresponds to episodic memory, and "knowing" to refer to the expression of noetic awareness, which corresponds to semantic memory. Remembering is characterised by recognition accompanied by the recollection of the mental representation constructed at encoding. Knowing is characterised by recognition achieved without access to information about the learning context.

Tulving (1985) and Gardiner and his associates (Gardiner, 2001; Gardiner & Richardson-Klavehn, 2000) operationalised these two states of awareness with the R/K paradigm. This has been applied particularly in recognition tasks and consists of asking participants to state the nature of their recollective experience at the time of recognition. The participants have to classify each recognised item into one of two categories: "Remember" (R) or "Know" (K). An "R" response involves the participant's recollection of specific, previously encountered contextual details, while a "K" response indicates that the participant is sure that the item is a target but without any specific contextual recollection of the previously presented item. Gardiner and Conway

Address correspondence to: David Clarys, Université François Rabelais, Département de Psychologie, UMR-CNRS 6234 "Centre de recherches sur la cognition et l'apprentissage", 3 rue des Tanneurs, BP 4103, F-37041 Tours Cedex 1, France. E-mail: david.clarys@univ-tours.fr

This research was supported by the Collaborative Workshop Scheme 170-25-0008 of the AHRC, CNRS, ESRC, and MESR. The authors thank two anonymous reviewers for their helpful comments on an earlier version of this manuscript.

http://www.psypress.com/memory DOI:10.1080/09658210802188301

(1999) suggested adding another category of response, ‘‘Guess’’ (G), when participants are not sure whether they saw the item during the learning task or not. This category avoids the possibility of participants choosing the ‘‘K’’ response when they are not sure that they have studied the item. Numerous experimental manipulations have strengthened this distinction, showing differential effects on ‘‘R’’ and ‘‘K’’ responses (for reviews, see Clarys, 2001; Gardiner, 2001).

Several studies have assessed the effects of ageing using the R/K paradigm, and a particularly compelling distinction between ‘‘R’’ and ‘‘K’’ responses has been observed. As a whole, two patterns of results emerge. Some studies have found that age is only associated with a decrease in Remember responses (Bugaiska et al., 2007; Bunce, 2003; Clarys, Isingrini, & Gana, 2002; Comblain, D’Argembeau, Van der Linden, & Aldenhoff, 2004; Fell, 1992; Lövden, Rönnlund, & Nilson, 2002; Perfect & Dasgupta, 1997), while others have also found an increase in the number of ‘‘K’’ responses (Bastin, Van der Linden, Michel, & Friedman, 2004; Bunce & Macready, 2005; Parkin & Walter, 1992; Perfect, Williams, & Anderton-Brown 1995; Piolino et al., 2006; Prull, Dawes, Martin, Rosenberg, & Light, 2006). Older adults are less likely to report recollective experience accompanying their recognition responses and more likely to report noetic consciousness. In a close approach, the studies that used the process-dissociation procedure (Jacoby, 1991, 1998) have shown a similar pattern of results. Indeed they observed no age-related differences in familiarity but an age-related decrease on recollection when process estimates were derived from the inclusion/exclusion method (for review, see Light, Prull, Lavoie, & Healy, 2000). It would thus be of interest to find an explanation for this decrease in autonoetic consciousness and highlight the factors involved.

One possible explanation for the differences in the proportion of R responses between younger and older people concerns executive functioning. Executive control is a multi-component construct that consists of a range of different processes that are involved in the planning, organisation, coordination, implementation, and evaluation of many of our non-routine activities (Glisky, 2007). The executive decline hypothesis for age-related decrease in cognitive performance (West, 1996), and particularly for memory, has received considerable empirical support (for reviews, see Moscovitch & Winocur, 1992; Parkin, 1997). This hypothesis is based on neurobiological and neuropsychological evidence. It suggests that age-related declines in memory may be due to a selective decline in executive functions, traditionally thought to be associated with the functioning of the frontal lobes, which seem to be the area of the brain that is the earliest and most extensively affected by ageing (Raz, 2000; West, 1996). Further evidence for the role of executive functioning comes from studies showing that older participants perform less well than younger ones in tasks in which patients with frontal lobe damage also show impaired performance, such as control of interference (Dempster, 1992), memory for temporal order (Fabiani & Friedman, 1997; Parkin, Walter, & Hunkin, 1995), metamemory (Souchay, Isingrini, & Espagnet, 2000), and conscious awareness (Bunce, 2003; Parkin & Walter, 1992). Both groups are also impaired in source memory tasks (Craik, Morris, Morris, & Loewen, 1990; Glisky, Polster, & Routhieux, 1995), which can be considered as a deficit in the ability to encode the spatial and temporal context associated with an event (Parkin & Walter, 1992). All these observations have led to the hypothesis that age-related memory deficit may be due to a decline in executive functions.

The few studies that have investigated this possibility through the Remember/Know paradigm have produced conflicting results. One study showed correlations between measures of executive functioning and the amount of reported recollective experience in the oldest group of participants (Parkin & Walter, 1992), while other studies found weak (Bunce & Macready, 2005; Perfect & Dasgupta, 1997) or no evidence (Perfect et al., 1995). Parkin and Walter (1992) found that higher levels of ‘‘R’’ responding by the older adults were reliably correlated with better performance on the Wisconsin Card Sorting Test (WCST-Modified, Nelson, 1976). These data suggest that contextually based recognition (‘‘R’’ responses) decreases as executive function declines. Bunce and Macready (2005) manipulated the time available for encoding operations and also recorded independent measures of executive functions and processing speed. They showed that processing speed, but not executive functioning, accounted for age-related variance in both remembering and knowing under the longer encoding condition. However, as the authors acknowledged, this result could be explained by the fact that the frontal tasks chosen (such as the FAS Word Fluency Test) did not assess the executive processes involved in elaborative rehearsal and structuring with sufficient rigour. In a recent study, Bugaiska et al. (2007) investigated the relationships between the age-related decline in remembering, processing speed, and executive function. This function was assessed using a single complex executive task, the Wisconsin Card Sorting Test. The results showed that the effect of age in recollection experience is determined by executive function and not by diminution of processing speed.

As observed by the above authors, the association of the R/K paradigm and the executive decline hypothesis (West, 1996) provides some interesting avenues for future research. So the present study was conducted not to oppose again the executive-ageing hypothesis and the speed mediation hypothesis, but to better understand the role of executive function. More specifically we studied the precise nature and organisation of executive functions involved in the age-related decrease in remembering, using the recent theoretical model of executive control proposed by Miyake et al. (2000). This model suggested that there are three specific executive functions: shifting between tasks or mental sets, updating, and inhibition of prepotent responses. Shifting ability involves the disengagement of an irrelevant task set and the active engagement of a relevant task set, as well as the capacity to perform a new operation when faced with proactive interference or negative priming. Updating is the capacity to control and code incoming information according to its relevance to the task. This ability enables old, non-relevant information in working memory to be replaced by new, more relevant information. Inhibition of prepotent responses refers to the ability to deliberately inhibit dominant or automatic irrelevant responses. Miyake et al. (2000) showed that these three specific functions are clearly distinguishable but not completely independent, seeming to possess some underlying commonalities.

The few previous studies that have examined executive functioning in the age-related deficit in remembering used only complex executive tasks and produced inconsistent results. Furthermore, none refers to an executive function model, and the tests used in these studies were not sufficiently specific. The main objective of the present study was to clarify these conflicting results and to better understand the role of executive function, highlighting the nature of the executive process involved. The originality of our research is to test the executive hypothesis through the recent theoretical model of executive functioning proposed by Miyake et al. (2000). We combined the executive hypothesis and the two-states-of-awareness approach (Gardiner, 2001; Tulving, 1985) to investigate the role of the three specific and complex executive functions in age-related decrements in recollective experience. To date, no study has been conducted to examine Miyake et al.'s (2000) model in the context of state of awareness. The first objective of this study was to confirm the age-related difference in R responses. For K responses the predicted pattern of results is less clear because some authors have found an age-related difference while others have not. The second objective was to test the hypothesis that remembering is dependent on executive functions and that knowing is not. If this were true, "Remember" responses would be related to specific and complex executive functions but "Know" responses would not. The third and main objective was to examine the hypothesis that age-related declines in executive functions explain the observed decline in "Remember" responses during ageing. We hypothesised that specific executive functions, rather than a global decline in such functions, will account for the effect of age on "Remember" responses.

METHOD

Participants

A total of 88 adults living in a medium-sized metropolitan area participated in the study and were divided into two age groups. The first consisted of 44 younger adults (age range 18–33 years) and the second of 44 older adults (age range 61–85 years). All the participants came from the general community and lived in their own homes. They were screened for possible dementia with the Mini Mental States Examination (MMSE, Folstein, Folstein, & McHugh, 1975) and for depression with the Geriatric Depression Scale (GDS; Yesavage et al., 1983). Only participants who obtained a score above the cut-off of 27 points on the MMSE and a score below the cut-off of 10 points on the GDS were included in the study.

The characteristics of the two groups are summarised in Table 1. The younger adults had more years of education than the older ones, but the older adults tended to perform better ($p = .07$)

TABLE 1
Means and standard deviations of participants' characteristics for the two age groups

	Young ($n = 44$)		*Old* ($n = 44$)		
	M	*SD*	*M*	*SD*	$F(1, 86)$
Age (years)	24.07	3.45	70.75	6.54	
Education (years)	12.14	2.20	10.55	3.72	5.97*
Mill Hill	30.14	6.19	32.57	6.30	3.34§

§$p = .07$; *$p < .05$.

on the Mill Hill Vocabulary Test (Deltour, 1993), a multiple-choice synonym vocabulary test.

Materials and procedure

Participants performed a recognition memory test using the Remember/Know/Guess method, and tests of executive function (Wisconsin Card Sorting Test, Number–letter task, 2-back test, and Stroop Colour-Word Test). All participants were tested individually and were informed that the experiment involved memory measures.

Remember Know/Guess measures

For the R/K/G paradigm, the material was the same as that used by Clarys et al. (2002) and consisted of two alternate study sets of 36 taxonomically unrelated concrete words. For each set, two different random orders were created. The sets were generated in such a way that the two lists were matched for word frequency and the number of letters per word. One set was presented at encoding and these words were used as target items in the following recognition test, while the other set provided the lures. Half the participants were presented with one set and half with the other, and they were not told how many items they had previously seen. The two sets of stimuli were counterbalanced across the two age groups. For the study phase, the words were presented on a computer screen at the rate of 5 s/word using Microsoft Power Point. The participants were told to read the words aloud and to remember them for a later test. The test phase was introduced following a retention interval of 5 minutes. The Stroop Colour-Word test (SCWT; Stroop, 1935) was administered during this interval and is described in the executive function section below.

For the recognition test, the complete set of 72 words (36 targets and 36 fillers) was presented in random order on the computer screen using Microsoft Power Point. For each word, the participants were asked if they recognised it from the earlier list. In addition, for each recognised word they had to indicate if their response was based on Remembering (R), Knowing (K), or Guessing (G). They were instructed to indicate an "R" response when the recognised word evoked some specific recollection from the learning sequence; for example, remembering a word because it brought to mind a particular association, image, or some other personal experience, or because something about its appearance or position could be recalled. "K" responses were to be given for the words that they felt confident about recognising but without any specific conscious recollection from the learning sequence. "G" responses were for words that they did not feel confident about recognising, and was used to avoid participants indicating a "K" response if they were not absolutely sure that they had seen the word in the study list. After the recognition phase, participants were asked to explain at least two of their Remember and two Know judgements to ensure that they had used the two types of response correctly: for R responses they had to give episodic details associated with the word encoding, and for K responses they had to show that they recognised the word but could not remember any specific detail about studying it. No participant was excluded on the basis of their explanations.

The dependent measures studied here were the proportion of overall correct recognitions (hits/targets) and false alarms (false alarms/lures), the proportion of correct recognitions and false alarms for "R", "K", and "G" responses, and the proportions of hits minus false alarms for overall recognition and for "R" and "K" responses. Data for correct and false Guess responses are presented in the tables but they were not analysed because they were only used to enhance the quality of K responses, and the number of responses was deemed to be too low.

Executive functioning tests

As in Miyake et al.'s study (2000), executive functioning was assessed using two kinds of executive test: complex executive tasks tapping various executive functions, and relatively simple executive tasks predominantly tapping each of the following specific executive functions: shifting, updating, and inhibition. The specific tasks were selected on the basis of proposals formulated by Miyake et al. (2000).

Wisconsin Card Sorting Test. The Wisconsin Card Sorting Test (WCST, modified by Nelson, 1976) is a standardised test designed to measure set formation and attentional shift, and as such is thought to assess complex executive functioning. It was administered and scored using standard procedures. This test requires participants to sort cards with geometric drawings varying in colour (yellow, green, red, or blue), shape (star, circle, cross, or square), and number (1, 2, 3, or 4), based on information provided by the examiner. The sorting rule changes throughout the test, thereby assessing the participant's ability to shift cognitive set. The WCST provides several scores and the specific measure given here is the number of perseverative errors, which are those most affected by age and the most representative of the executive function factor (Bryan, Luszcz, & Pointer, 1999).

Number–letter task. This task (Rogers & Monsell, 1995) was used to measure the shifting executive component. A number–letter pair (e.g., 5A) was presented in one of four boxes of a table. Participants were instructed to indicate whether the number was odd or even when the number–letter pair was presented in one of the top two boxes (number task), and whether the letter was a vowel or a consonant when the number–letter pair was presented in one of the bottom two boxes (letter task). The number–letter pair was presented only in the top two boxes for the first list of 32 target trials, only in the bottom two boxes for the second list of 32 target trials, and randomly in all four boxes for the third list of 32 target trials (switch trials). Thus, the trials with the first two lists required no task switching, whereas the third list required participants to shift between these two types of categorisation operations. In all trials, participants responded by ticking one answer from a choice of four: "Odd", "Even", "Consonant", "Vowel". They were instructed to complete each list quickly and accurately, and completion times were measured. The cost of shifting between the two types of categorisation operations was calculated as the difference between the time to complete the third list, which required a mental shift, and the average of the times to complete the first two lists in which no shift was necessary. This shift cost served as the dependent variable.

2-back test. The 2-back letter task (Gevins & Cutillo, 1993) is hypothesised to tap the updating executive component. In this test the participant listens to a continuous sequence of letters and must decide and say whether each letter matches the one presented two back in the sequence. The letter list was composed of 30 items and the score was the number of correct responses.

Stroop Colour-Word test. The SCWT (Stroop, 1935) was used to measure the inhibition executive component. This task involves three subtests each displaying 100 stimuli. In the first (word reading), the participant is required to read words printed in black ink representing names of some basic colours. In the second subtest (colour naming), participants have to name the colour of crosses (XXX). In the last subtest (colour-word interference), they have to name the colour of the colour-word printed in incongruously coloured ink (e.g., the word "red" is written in green). In each subtest participants were required to name the colours aloud as quickly as possible for 45 seconds, and the number of correct responses was recorded. An interference score was computed as follows: colour-word interference score – [(word reading score × colour naming score)/(word reading score × colour naming score)].

RESULTS

Remembering, Knowing, and Executive measures

The means and standard deviations of hits, false alarms, and hits minus false alarms for overall recognition, "R", "K", and "G" responses, and the scores for executive measures are presented in Table 2. Separate analyses of variance (ANOVA) with age as a between-participants factor were performed on these measures. The analyses of hits revealed a significant age-related effect on

TABLE 2
Means and standard deviations for hits, false alarms, hits minus false alarms, and executive tasks as a function of age group

	Young (n =44)		*Old* (n =44)		
	M	*SD*	*M*	*SD*	F(1, 86)
Hits					
Overall recognition	.68	.13	.58	.18	8.11**
Remember	.30	.13	.23	.16	4.95*
Know	.30	.14	.28	.17	0.47 *ns*
Guess	.08	.05	.07	.07	–
False alarms					
Overall recognition	.15	.13	.22	.17	5.05*
Remember	.02	.04	.06	.11	4.64*
Know	.07	.07	.09	.07	1.35 *ns*
Guess	.06	.06	.07	.08	–
Hits minus False alarms					
Overall recognition	.53	.16	.36	.15	25.67***
Remember	.28	.13	.17	.11	17.62***
Know	.23	.14	.19	.15	1.67 *ns*
Executive function					
WCST	0.57	1.37	4.43	5.31	21.83***
2-back test	23.09	2.14	20.30	2.97	18.89***
Number–letter test	25.23	10.90	39.79	17.58	25.63***
SCWT	3.80	7.94	−7.93	13.62	24.36***

WCST: Wisconsin Card Sorting Test; SCWT: Stroop Colour-Word Test; *p <.05; **p <.01; ***p <.001; *ns*: non-significant.

overall recognition and on ‘‘R’’ responses, but no such effect on ‘‘K’’ responses. For the false alarms the separate analyses of variance showed a significant age-related increase in overall recognition and in ‘‘R’’ responses, but not in ‘‘K’’ responses. For hits minus false alarms an age-related decrease was observed for overall recognition and for ‘‘R’’ responses. For ‘‘K’’ responses there was no age-related effect. In this way, the older participants demonstrated a decrease in recognition, and more specifically in ‘‘R’’ responses. Thus, in line with our hypothesis, recognition associated with conscious recollection (‘‘R’’ responses) declined with age, whereas recognition without conscious recollection (‘‘K’’ responses) did not. However, we conducted a power analysis for the null findings of age and ‘‘K’’ responses. Our sample size ($n = 88$) provides a power of 0.22 at an alpha level of 0.05. Therefore our sample size does not have sufficient statistical power to detect a potential effect of age on ‘‘K’’ responses. From this sample size one cannot conclude that there is no age-related difference in ‘‘K’’ responses.

For executive tasks, as predicted, separate analyses of variance indicated a significant age effect on all of these measures. Thus, our study demonstrated an age-related decrease in executive functioning.

Correlations between executive functioning and Remember/Know measures (hits minus false alarms)

Correlations were performed to determine whether there was any relationship between executive measures and the two states of awareness. For ‘‘R’’ and ‘‘K’’ responses the measure used was hits minus false alarms. They were computed for each age group separately, and for the two age groups combined after age group had been partialled out. As recommended by Bryan and Luszcz (1996), the age group variable was used rather than individual age in the correlations and regression analyses. As participants were selected from two age groups, age was not normally distributed in this study, and correlations involving this type of distribution tend to be inflated due to overestimation of the range of scores. Therefore, age was coded as a qualitative variable (young = 1, old = 2). The correlation matrix within each age group separately (the younger below and the old above the diagonal) is presented in Table 3. Table 4 presents these correlations for all the participants

TABLE 3
Pearson correlations: Younger and older groups

Older / *Younger*	*1* *WCST*	*2* *2-back test*	*3* *Number–letter test*	*4* *SCWT*	*5* *Remember*	*6* *Know*
1. WCST	–	−.25[§]	.29*	−.14	−.27[¶]	–.22
2. 2-back test	.31*	–	−.35*	−.35*	.71***s	–.16
3. Number–letter test	−.06	−.17	–	−.23	−.35*	–.04
4. SCWT	.00	−.05	−.25	–	.30*	.07
5. Remember	.03	.31*s	.00s	−.07	–	−.33*
6. Know	−.04	−.01	−.14	.14	−.52***	–

Pearson correlations between Remember, Know responses, and executive function measures for the younger (below the diagonal; $n = 44$) and for the older group (above the diagonal; $n = 44$).

WCST: Wisconsin Card Sorting Test; SCWT: Stroop Colour-Word Test; [§]$p = .10$; [¶]$p = .08$; *$p < .05$; **$p < .01$; ***$p < .001$; s: significant difference between younger and older group correlations.

after age group was partialled out. For younger participants "R" responses only correlated significantly to the 2-back test whereas there was no significant correlation between "K" responses and executive function tasks. For older participants all executive measures correlated with "R" responses but not with "K" responses. The correlation between "R" responses and the 2-back test was very strong (.71) and was significantly greater in the older group than in the younger one (.31). When the two groups were combined and age group partialled out (Table 4), the analysis revealed that "R" responses correlated with the 2-back test and tended to correlate ($p = .08$) with the number–letter test. Conversely, there was no significant correlation with "K" responses. Thus, a correlational dissociation between "R" and "K" responses was observed, indicating that "R" responses correlated with executive tasks, whereas "K" responses did not correlate with any measure.

Hierarchical regression analyses

The role of the executive function tasks in the remembering variance was assessed using hierarchical multiple regression analyses. As shown by the correlations matrix there was a strong correlation between "R" responses and the 2-back test. To exclude the possibility that this measure, which has the greatest first-order correlation with "R" responses, can alone account for the greatest proportion of variance in "R", three separate hierarchical regression analyses were conducted in order to test alternative models (order of entry). For "R" responses the measure used was hits minus false alarms. The results of these analyses are shown in Table 5. In the first analysis (Analysis 1) we entered first the three executive tasks least correlated with R responses: the number–letter test, the WCST, and the SCWT. Then we added the age group to examine whether prior entry of these three variables reduced the contribution of age group to a non-significant amount. Finally we entered the 2-back test to see whether this test accounted for a significant proportion of variance in R responses once age group was partialled out. The same procedure was repeated for Analysis 2, with the 2-back test entered before age group to examine whether prior entry of this test reduced the contribution of age group to a non-significant

TABLE 4
Pearson correlations: All participants

	WCST	*2-back test*	*Number–letter test*	*SCWT*	*Remember*
2-back test	−.15				
Number–letter test	.23*	−.30**			
SCWT	−.10	.23*	−.24*		
Remember	−.16	.52***	−.19[§]	.15	
Know	−.17	−.10	−.08	.09	−.42***

Pearson correlations between Remember, Know responses, and executive function measures for all the participants ($n = 88$) after age group was partialled out.

WCST: Wisconsin Card Sorting Test; SCWT: Stroop Colour-Word Test; [§]$p = .08$; *$p < .05$; **$p < .01$; ***$p < .001$.

TABLE 5
Hierarchical regression analyses predicting "R" responses (hits minus false alarms) from age group and executive measures

Analyses	*Variable*	R^2	R^2 *modified*
Analysis 1	Number–letter task	.11	.11**
	WCST	.15	.04*
	SCWT	.18	.03
	Age group	.22	.04*
	2-back	.40	.18***
Analysis 2	Number–letter task	.11	.11**
	WCST	.15	.04*
	SCWT	.18	.03
	2-back	.39	.21***
	Age group	.40	.01
Analysis 3	2-back	.37	.37***
	Number–letter task	.38	.01
	WCST	.39	.01
	SCWT	.39	.00
	Age group	.40	.01

$n = 88$.
WCST: Wisconsin Card Sorting Test; SCWT: Stroop Colour-Word Test; *$p < .05$; **$p < .01$; ***$p < .001$.

amount. Finally, in the third analysis (Analysis 3), the 2-back test was entered first to see whether the other executive tasks and age group accounted for a significant proportion of variance in R responses after this measure was partialled out.

Analysis 1 shows that the number–letter task, the WCST, and the SCWT predicted 18% of the variance in remembering when entered first and that, after controlling for these measures, age group added a significant 4% to the variance. Analysis 1 indicates that the 2-back test, after controlling for the other executive tasks and age group, added a significant 18% to the variance in R responses. Analysis 2 shows that after controlling for the number–letter task, the WCST and the SCWT, the 2-back test added 21% to the variance in remembering. Age group no longer predicted "R" responses once executive functioning had been controlled. Finally, Analysis 3 indicates that the 2-back test predicted 37% of the variance in remembering when entered first. The other executive tasks and age group no longer predicted R responses after the 2-back test had been entered. These analyses indicate that the 2-back test is the main measure explaining variance in "R" responses, and more specifically, the age-related decline in remembering.

DISCUSSION

The aim of this study was to examine the precise nature and organisation of executive functions involved in the age-related decline in remembering, through a recent executive functions model (Miyake et al., 2000). First, we evaluated the effects of age in the two states of awareness. In line with our hypothesis, an age-related difference in the nature of awareness during recognition was observed. In accordance with previous studies (Bastin et al., 2004; Bugaiska et al., 2007; Bunce, 2003; Bunce & Macready, 2005; Clarys et al., 2002; Comblain et al., 2004; Fell, 1992; Lovden et al., 2002; Parkin & Walter, 1992; Perfect & Dasgupta, 1997; Perfect et al., 1995; Piolino et al., 2006; Prull et al., 2006), recognition with conscious recollection (R) was found to be impaired in ageing, whereas Know responses were not. Thus, the age-related decrease observed in overall recognition could be explained by the selective decline of responses associated with recollective experience, older adults failing to recollect specific contextual details that they had previously encountered. However, the power analysis indicated that this sample size is not sufficient to draw conclusions regarding the age-related difference in "K" responses.

The main objective of this study was to investigate the relationships between ageing, specific executive functions, and states of awareness. In line with the executive decline hypothesis (West, 1996) we found that older participants showed a marked decline in both complex and specific executive tasks. The results also indicated that the "R" responses were correlated with all the executive measures in the older group and only with the 2-back test in the younger group. When all the participants were included and the age group partialled out, "R" responses still correlated significantly with the 2-back test and there was a trend towards significance for the number–letter test. By contrast, there was no significant correlation between "K" responses and executive measures. It therefore appears that remembering is related to executive function, and particularly to the 2-back test, which is frequently used as a measure of the updating process. Our results, showing a correlational dissociation between "R" and "K" responses, are consistent with previous studies demonstrating that remembering and knowing can be dissociated by manipulating different variables (Clarys, 2001; Gardiner, 2001). These findings support the hypothesis of a functional dissociation between Remember and Know responses and provide data regarding their nature, indicating that "R", but not "K", responses depend on executive functions that correspond to strategic processes.

Three hierarchical regression analyses were also conducted to examine which executive task accounted for a significant proportion of R response variance, and whether the prior entry of these measures reduced the contribution of age group to a non-significant amount. The analyses indicated that the most important executive measure was the 2-back test, considered to evaluate the updating capacity. This measure appeared to be the best predictor of the variance in R responses and of the effects of age in remembering. The other executive tasks studied here seemed to be less involved in the Remember responses. The notion that executive deficit mediates the age-related decline in remembering has produced conflicting results in the literature. Our finding is consistent with two previous studies (Bugaiska et al., 2007; Parkin & Walter, 1992) but conflicts with others (Bunce & Macready, 2005; Perfect & Dasgupta, 1997; Perfect et al., 1995). These discrepant findings may be attributed to multiple confounds between participants, stimuli, timing, and various other important factors as the different tests used. For example, Bunce and Macready (2005) showed that processing speed but not executive functioning explained age-related variance in remembering. They used the digit-symbol substitution test (DSST) of the WAIS-R (Wechsler, 1981) as a speed test, but Parkin and Java (1999) showed that the DSST attenuated age-related differences in executive function in contrast to the digit cancellation task, which is a speed task requiring virtually no memory load, minimal attentional demands, and only a small motor component. Thus one can suggest that the DSST assessed executive functioning more than processing speed (Baudouin, Clarys, Vanneste, Isingrini, 2008). Therefore, while Bunce and Macready's (2005) study did not provide evidence that executive functioning is involved in the age-related difference in remembering, this could be because they used the DSST, which is based on high-level processing.

These executive functions may be involved at different stages of the initiation and control of memory processes. The updating process assumed to be evaluated by the 2-back test may be strongly involved in the elaboration and control of mental representation in memory during presentation of the material and during the recognition stage. This function could allow suitable strategies to be used at encoding and recognition to improve the memory trace, and may improve the learning and retrieval of information and the associated contextual details needed for recognition based on conscious recollection. This supports the notion that frontal lobe dysfunction does not produce a decrease in the storage capacity of memory but modifies the strategic processes accompanying mnemonic activities, such as initiation, execution, and the control of strategies occurring during information encoding and retrieval (Moscovitch, 1992). For example, during the encoding stage the updating process may help initiate encoding strategies, and during retrieval it may help initiate a strategic retrieval search and check that information has been correctly recalled. Older participants are thus less likely to initiate the elaborate rehearsal and structured encoding strategies that may aid conscious recollection and therefore produce fewer Remember responses.

The results of the present study support the hypothesis that updating is an important function involved in the age-related decrease in remembering. Executive functioning was assessed using two kinds of executive test: complex executive tasks tapping various executive functions, and relatively simple executive tasks predominantly tapping shifting, updating, and inhibition. However, the construct validities of complex executive tasks have not been completely established (Phillips, 1997; Rabbitt, 1997), despite their broad acceptance as measures of executive functioning. Many popular executive tasks seem to have been validated only on the criterion of being somewhat sensitive to frontal lobe damage, and the precise nature of the executive processes involved in the performance of these tasks is underspecified (Miyake et al., 2000). These tasks are not specific enough, and could involve both executive and non-executive processes. For these reasons, in contrast to specific executive measures, complex executive tasks do not appear to be able to explain the links between remembering responses and executive functioning. Our study therefore examined more specifically the precise nature and organisation of the executive functions involved in the age-related decline in remembering, including three specific tasks supposed to evaluate three relatively circumscribed lower level functions. However, each executive function was measured with only one indicator. Because of the potential for measurement error and for overlapping processes, it is not really possible to attribute any one task (2-back task) to a single process (updating). Another difficulty with the assessment of the updating function is that the 2-back test could involve processes of recognition memory similar to those involved in remembering. However the 2-back test is a short-term auditory memory task, whereas the episodic memory task involves long-term visual memory. To address these issues and confirm our results, further studies need to be conducted with at least three indicators for each of the specific executive functions.

In summary, the results of the present study support the hypothesis that specific executive deficits account for the age-related decline in memory performance. Miyake et al.'s theoretical model (2000) studied here seems to offer a useful approach for understanding executive functioning in ageing. The regression analysis strongly suggests that age-related differences in remembering can be accounted for by individual differences in executive measures and particularly in the 2-back test, which is supposed to tap the updating function. Conversely, ''Knowing'' was found not to depend on executive function and so was unaffected by ageing. The association of the two-states-of-awareness theory and the executive decline hypothesis, through the executive functioning model of Miyake et al. (2000), seems to provide some interesting results that need to be supported by further research investigating more specifically the close link between executive function and conscious awareness with more executive tasks for each specific executive component.

REFERENCES

Bastin, C., Van der Linden, M., Michel, A. P., & Friedman, W. J. (2004). The effects of ageing on location-based and distance-based processes in memory for time. *Acta Psychologica*, *116*, 145–171.

Baudouin, A., Clarys, D., Vanneste, S., & Isingrini, M. (2008). *Executive functioning and processing speed in age-related effect in memory: Contribution of a coding task.* Manuscript submitted for publication.

Bryan, J., & Luszcz, M. A. (1996). Speed of information processing as a mediator between age and free-recall performance. *Psychology & Ageing*, *11*, 3–9.

Bryan, J., Luszcz, M. A., & Pointer, S. (1999). The contribution of executive function and processing resources to age differences in the effects of strategy use on free recall. *Ageing; Neuropsychology and Cognition*, *6*(4), 273–287.

Bugaiska, A., Clarys, D., Jarry, C., Taconnat, L., Tapia, G., Vanneste, S., et al. (2007). The effect of ageing in recollective experience: The processing speed and executive functioning hypothesis. *Consciousness & Cognition*, *16*(4), 797–808.

Bunce, D. (2003). Cognitive support at encoding attenuates age differences in recollective experience among adults of lower frontal lobe function. *Neuropsychology*, *17*, 353–361.

Bunce, D., & Macready, A. (2005). Processing speed, executive function, and age differences in remembering and knowing. *The Quarterly Journal of Experimental Psychology*, *58A*(1), 155–168.

Clarys, D. (2001). Psychology of human memory: Theoretical and methodological progress. *L' Année Psychologique*, *101*, 495–519.

Clarys, D., Isingrini, M., & Gana, K. (2002). Ageing and episodic memory: Mediators of age differences in remembering and knowing. *Acta Psychologica*, *109*(3), 315–329.

Comblain, C., D'Argembeau, A., Van Der Linden, M., & Aldenhoff, L. (2004). The effect of ageing on the recollection of emotional and neutral picture. *Memory*, *12*(6), 673–684.

Craik, F. I. M., Morris, L. W., Morris, R. G., & Loewen, E. R. (1990). Relations between source amnesia and frontal lobe functioning in older adults. *Psychology & Ageing*, *5*, 148–151.

Deltour, J. J. (1993). *Echelle de vocabulaire de Mill Hill de J. C. Raven. Adaptation française et normes europeennes du Mill Hill et du Standard Progressive Matrices de Raven (PM38).* Braine-le-Chateau: Editions l'application des techniques modernes.

Dempster, F. N. (1992). The rise and fall of the inhibitory mechanism: Toward a unified theory of cognitive development and aging. *Developmental Review*, *12*, 45–75.

Fabiani, M., & Friedman, D. (1997). Dissociations between memory for temporal order and recognition memory in aging. *Neuropsychologia*, *35*, 129–141.

Fell, M. (1992). Encoding retrieval and age effect on recollective experience. *The Irish Journal of Psychology*, *13*, 62–78.

Folstein, M. F., Folstein, S. F., & Mc Hugh, P. R. (1975). Mini-Mental State: A practical method for grading the cognitive state of patient for the clinician. *Journal of Psychiatric Reseach*, *12*, 189–198.

Gardiner, J. M. (2001). Episodic memory and autonoetic consciousness: A first person approach. *Philosophical Transactions of the Royal Society London B*, *356*, 1351–1361.

Gardiner, J. M., & Conway, M. A. (1999). Levels of awareness and varieties of experience. In B. H. Challis & B. M. Velichkovsky (Eds.), *Stratification in cognition and consciousness* (pp. 237–254). Amsterdam/Philadelphia: John Benjamin Publishing Company.

Gardiner, J. M., & Richarson-Klavehn, A. (2000). Remembering and knowing. In E. Tulving & F. I. M. Craik (Eds.), *The Oxford handbook of memory*. Oxford, UK: Oxford University Press.

Gevins, A., & Cutillo, B. (1993). Spatiotemporal dynamics of component processes in human working memory. *Electroencephalography and Clinical Neurophysiology*, *87*(3), 128–143.

Glisky, E. L. (2007). Changes in cognitive function in human aging. In D. Riddle (Ed.), *Brain aging: Methods, models, and mechanisms* (pp. 3–20). New York: CRC Press.

Glisky, E. L., Polster, M. R., & Routhieaux, B. C. (1995). Double dissociation between item and source memory. *Neuropsychology*, *9*, 229–235.

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. (1998). Invariance in automatic influences of memory: Toward a user's guide for the process-dissociation procedure. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *24*, 3–26.

Light, L. L., Prull, M. W., LaVoie, D. J., & Healy, M. R. (2000). Dual process theories of memory in old age. In T. J. Perfect & E. A. Maylor (Eds.), *Models of cognitive ageing* (pp. 238–300). Oxford, UK: Oxford University Press.

Lövdén, M., Rönnlund, M., & Nilson, G.-L. (2002). Remembering and knowing in adulthood: Effects of enacted encoding and relations to processing speed. *Aging, Neuropsychology, Cognition*, *9*, 184–200.

Miyake, A., Friedman, N., Emerson, M., Witzki, A., Howerter, A., & Wager, T. (2000). The unity and diversity of executive functions and their contributions to complex frontal lobe tasks: A latent variable variable analysis. *Cognitive Psychology*, *41*, 49–100.

Moscovitch, M. (1992). Memory and working-with-memory: A component process model based on modules and central systems. *Journal of Cognitive Neuroscience*, *4*, 257–267.

Moscovitch, M., & Winocur, G. (1992). The neuropsychology of memory and ageing. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of ageing and cognition* (pp. 315–371). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Nelson, H. E. (1976). A modified card sorting test sensitive to frontal lobe deficits. *Cortex*, *12*, 313–324.

Parkin, A. J. (1997). Normal age-related memory loss and its relation to frontal lobe dysfunction. In P. Rabbitt (Ed.), *Methodology of frontal and executive function* (pp. 177–190). Hove, UK: Psychology Press.

Parkin, A. J., & Java, R. I. (1999). Deterioration of frontal lobe function in normal aging: Influences of fluid intelligence versus perceptual speed. *Neuropsychology*, *13*, 539–545.

Parkin, A. J., & Walter, B. M. (1992). Recollective experience, normal aging, and frontal dysfunction. *Psychology & Aging*, *7*, 290–298.

Parkin, A. J., Walter, B. R., & Hunkin, N. M. (1995). Relationships between normal aging, frontal lobe function and memory for temporal and spatial information. *Neuropsychology*, *9*, 304–312.

Perfect, T. J., & Dasgupta, Z. R. R. (1997). What underlies the deficit in reported recollective experience in old age. *Memory & Cognition*, *25*, 849–858.

Perfect, T. J., Williams, R. B., & Anderton-Brown, C. (1995). Age differences in reported recollective experiences are due to encoding effects, not response bias. *Memory*, *3*, 169–184.

Phillips, L. H. (1997). Do "frontal tests" measure executive function? Issues of assessment and evidence from fluency tests. In P. Rabbitt (Ed.), *Methodology of frontal and executive functions* (pp. 191–213). Hove, UK: Psychology Press.

Piolino, P., Desgranges, B., Clarys, D., Guillery-Girard, B., Taconnat, L., Isingrini, M., et al. (2006). Autobiographical memory, autonoetic consciousness and self-perspective in aging. *Psychology and Aging*, *21*(3), 110–125.

Prull, M. W., Dawes, L. L. C., Martin, A. M., Rosenberg, H. F., & Light, L. L. (2006). Recollection and familiarity in recognition memory: Adult age differences and neuropsychological test correlates. *Psychology & Aging*, *21*(7), 107–118.

Rabbitt, P. N. (1997). Introduction: Methodologies and models in the study of executive function. In P. Rabbitt (Ed.), *Methodology of frontal and executive function*. Hove, UK: Psychology Press.

Raz, N. (2000). Ageing of the brain and its impact on cognitive performance: Integration of structural and functional findings. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of ageing and cognition. Second edition*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Rogers, R. D., & Monsells, (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of experimental psychology: General*, 124, 207–231.

Souchay, C., Isingrini, M., & Espagnet, L. (2000). Ageing, episodic memory, feeling-of-knowing, and frontal functioning. *Neuropsychology*, *2*, 299–309.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *89*, 669–679.

Tulving, E. (1983). *Elements of episodic memory*. Oxford, UK: Oxford University Press.

Tulving, E. (1985). Memory and consciousness. *Canadian Psychologist*, *26*, 1–12.

Wechsler, D. (1981). *Manual for Wechsler Adult Intelligence Scale–Revised*. San Antonio, TX: Psychological Corporation

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

Yesavage, J. A., Brink, T. L., Rose, T. L., Lum, O., Huang, V., Adey, M., et al. (1983). Development and validation of a geriatric depression screening scale – a preliminary report. *Journal of Psychiatric Research*, *17*(1), 37–49.