Pergamon

0028-3932(95)00097-6

Neuropsychologia, Vol. 34, No. 3, pp. 195–207, 1996

Printed in Great Britain
0028-3932/96 $15.00 + 0.00

Examination of the working memory components in normal aging and in dementia of the Alzheimer type

SYLVIE BELLEVILLE,*†‡ ISABELLE PERETZ†‡ and DOMINIQUE MALENFANT

†Centre de Recherche du Centre hospitalier Côte-des-Neiges, Montréal, Québec, Canada; and ‡Groupe de Recherche en Neuropsychologie, Département de Psychologie, Université de Montréal, Montréal, Québec, Canada

(*Received* 10 *August* 1994; *accepted* 2 *June* 1995)

Abstract—The verbal and attentional components of working memory were examined in patients with Alzheimer's disease, normal elderlies, and young controls. Patients with Alzheimer's disease, showed a reduced span but were sensitive to word length. This is indicative of a functional rehearsal procedure. However, the effect of phonological similarity on immediate recall was smaller in patients with Alzheimer's disease and these patients showed a depressed performance in tasks of phonological analysis. There was also a significant decrement in a task that assessed the attentional component of working memory. Examination of individual patterns of performance showed that the phonological deficiency was severe in a subgroup of patients while the attentional deficit was more general.

Key Words: working memory; Alzheimer's disease; normal aging; heterogeneity; phonological processing.

Introduction

Dementia of Alzheimer's type (DAT) is a degenerative disease associated with a variety of cognitive deficits. In its early course, one of the most prominent features of DAT is an impairment in memory functioning [for reviews, see 36, 46]. Understanding the nature of the memory impairment encountered in this neurological condition is of major theoretical concern. From a clinical perspective, a better comprehension of the memory impairments that are characteristic of DAT may facilitate its distinction from normal aging. Indeed, the diagnosis of Alzheimer's disease is established with certainty only when senile plaques and neurofibrillary tangles are detected following histopathological examination of the brain tissue [30]. This histopathological confirmation is most often done post mortem. Thus, when the patient is alive, the diagnosis depends on a thorough clinical investigation that will confirm the presence of a cognitive deterioration and exclude any other neurological, systematic, or psychiatric underlying factor potentially responsible for the deficit. This is complicated by the observation that the deficits observed in early DAT, mostly memory deficits, coincide with those observed in normal aging. Therefore, a major goal of the research in this domain is to distinguish the early cognitive manifestations of the disease from those that are found in normal aging.

Distinguishing DAT from aging is not an easy task. The difference between the two populations generally bears on the severity of the deficit, DAT representing an extreme version of normal deterioration due to aging. This has been shown within the working memory (WM) model of Baddeley [3]. DAT patients exhibit both a decrease in their span capacity [29, 52, 63, 70] and a lower performance on the classical Brown–Peterson procedure [19, 21, 32, 65] than that of normal aged-matched controls [for reviews, see 15, 33, 36, 45]. These anomalies in short-term recall have been attributed to a dysfunction of the attentional component of WM [3, 8, 43–45]. Before further discussing the nature of this particular attentional defect in DAT, it is necessary to first present an overview of the WM model.

WM is conceptualized as a multicomponent device responsible for holding and manipulating information

*Address for correspondence: Centre de Recherche du Centre hospitalier Côte-des-Neiges, 4565 Queen-Mary, Montréal, Québec, Canada H3W 1W5; fax: 514-340-3548.

while the subject is engaged in various processing and cognitive tasks [3–5]. It postulates the existence of a nonmodular attentional component, the central executive. This component is the depository and controller of the limited resources that are shared by the different slave systems (to be described hereafter). It is responsible for coordinating the demands coming from different sources, for example, WM and long-term memory. The central executive also sets the priorities of the system according to the requirements of the task [51, 61]. It is typically assessed by divided attention tasks or paradigms that manipulate the complexity of the task to be performed [3, 8, 14, 25, 44, 68].

The model also comprises modular slave systems responsible for the retention of information in particular codes. The phonological loop (recently labeled as such by Baddeley [4], but formerly known as the articulatory loop) contributes to the retention of verbal information. Within the phonological loop, two subcomponents are involved in the retention of verbal material: the phonological short-term store and the rehearsal procedure. The phonological short-term store holds verbal information, whether presented visually or auditorily, in the form of a phonological code. It has been repeatedly shown that the span capacity is greater when tested with sequences of phonologically dissimilar items than when tested with phonologically similar items [2, 18, 60]. The retention of verbal information within a phonological code is probably responsible for this phonological similarity effect as phonologically close items are more susceptible to mutual interference [49]. The capacity of the phonological short-term store is time limited and the model postulates the involvement of a rehearsal procedure that refreshes verbal information. There is considerable evidence to suggest that articulation plays a major role in that rehearsal procedure. For example, the span capacity is larger for short words than it is for long words [7], probably because the former are more rapidly pronounced than the latter (however, see [17, 20] for alternative interpretations). Both word length and phonological similarity effects can be used as indicators of the integrity of the phonological loop. These measures have been widely used to examine the phonological loop following neurological damage [12, 13, 57, 66, 67].

It was Miller in 1972 who first examined the verbal components of WM in DAT patients. He assessed the effect of phonological similarity on short-term recall of words in the auditory and visual modalities. While he did observe a phonological similarity effect in DAT patients in both modalities, its magnitude was significantly smaller than in normal elderly controls. In contrast, Morris [43] later observed normal phonological similarity and word length effects in DAT patients and attributed Miller's findings to a floor effect. If the latter interpretation is correct, the available evidence would suggest that the verbal component of WM is intact in DAT patients. Consequently, the short-term memory defect of DAT patients would result from an impairment at the level of another component, namely the central executive. This hypothesis has been empirically verified: DAT patients were found to be impaired in their ability to retain information while performing tasks of increasing demand [44]. Similar results were obtained by Baddeley and colleagues [8] who report a major divided attention deficit in patients with DAT, which worsens with the progression of the disease [9]. There is thus compelling evidence that a dysfunction of the central executive component underlies the short-term memory defect of DAT patients [8, 44–46]. Conversely, the slave components of WM would be functional within such a model of the cognitive deficits of DAT.

The particular pattern of spared and impaired performance depicted in the WM of DAT patients is similar to that proposed in normal aging. A number of authors have suggested that normal aging reduces the efficiency of the central executive component of WM. Compared to young subjects, aged subjects exhibit depressed performance in tasks that require increasing resource demands [24, 25, 35, 40, 47, 58], which has led some authors to argue for an attentional reduction on WM tasks. The phonological loop has, to our knowledge, never been directly assessed in normal aging but the implication is that it would remain unaffected [3]. If it is confirmed that aged subjects also experience a selective deficit of the central executive in WM, the pattern would take the form of a continuum between aging and DAT, the latter being more severely affected than the former. As mentioned earlier, this has major clinical and theoretical implications. Firstly, the sole observation of quantitative differences greatly complicates the early diagnosis of DAT. Secondly, the observation of a continuum suggests that DAT merely represents the end of a normal aging process.

However, there is evidence to suggest that aging and DAT are not only quantitatively but also qualitatively different since DAT patients show impairments in specific domains of cognition [39, 50]. A significant proportion of DAT patients develop language problems in the course of the disease [23]. Since there is a frequent association between linguistic difficulties and deficits of the phonological loop [1], it is reasonable to expect deficits at this level in a number of patients. The first goal of this study was therefore to reassess the phonological and length effects in the DAT population. Since problems at the phonological level are expected to occur in at least a few patients, three additional tasks were included to assess phonological abilities. These consist of two visual recoding tasks, which assess rhyme and homophony judgement for written words, as well as an auditory phonological discrimination task (as used in [13, 67]). One problem in past studies is that the different components of WM have never been assessed in the same patients: the phonological loop and central executive have been evaluated in different studies and therefore with patients who may differ in disease severity or in cognitive deterioration profile. Therefore, the central executive component was also assessed in these patients. The final goal was to test the notion of a quantitative gradient between DAT and normal aging. We therefore assessed the effect of normal aging on the components of WM by including a group of young subjects. This is particularly important because the effect of normal aging on the phonological loop has never been examined.

To summarize, the general objectives of this study are to show that the pattern of WM impairment observed in DAT patients can be qualitatively different from that of normal aging; that a subgroup of DAT patients can suffer from a dysfunctional phonological loop; and finally that averaging the performance of heterogeneous DAT patients, as is the case of other brain-damaged subjects, can hinder the true effect of the disease on cognition.

Method

Subjects

Three groups of subjects participated in this study: (1) patients with dementia of the Alzheimer's type, (2) normal elderlies, and (3) young subjects. The DAT group consisted of 20 patients (11 women and 9 men). Patients were diagnosed by independent neurologists as suffering from DAT and referred to our Research Center to participate in research on the characterization of dementia. As part of this larger project, 18 patients were tested with the PENO neuropsychological battery [28]. The battery includes various standard tests that assess four areas of cognitive functioning: memory, language, gnosis, and praxis. Clinical neuropsychologists tested the two remaining patients with similar standard evaluation tools. On the basis of these evaluations, the severity of dementia was estimated using the Reisberg Global deterioration scale [55]. Nine patients were classified in stage 3 of the disease, eight in stage 4 and three in stage 5. The patients used in the present study met the National Institute for Neurological Communicative Disorders, and Stroke–Alzheimer Disease and Related Disorders Association (NINCDS–ADRDA) criteria [41] for "probable" or "possible" Alzheimer's disease (with 17 and 3 patients, respectively). The three patients with possible Alzheimer's disease were conservatively diagnosed as such because their CT scan was not available. However, the clinical examination did not show any sign of focal neurological anomalies (i.e. sudden onset of the symptomatology, abrupt deterioration during the evolution, presence of focal neurological signs).

All patients had suffered from progressive worsening of memory problems for at least 6 months. They were free from neurological, systemic, or psychiatric disorders sufficient to produce dementia. They did not take any medication that is known to affect the central nervous system. Their age ranged from 52 to 82 years (mean age = 69.6), and their educational level ranged from 5 to 20 years (mean years of education = 10.8). None of the patients was institutionalized at the time of testing and they were all able to read and write. Patients were not paid for their participation in the study but were compensated for the cost of transportation to the hospital.

Twelve aged and 12 young normal subjects selected from a large pool of community members who volunteered to participate in research on cognition served as control subjects. The normal controls were noninstitutionalized, alert, and had no history of neurological problems, alcohol abuse, or psychiatric disorders. The average age for the group of elderlies was 65.6 (range 60–80) and the average age for the group of young subjects was 26 (18–39). Normal aged and DAT subjects did not differ according to their age ($t = 1.42$). The average educational level was 12.66 years for the group of aged subjects and 13.22 years for the young subjects. The normal subjects received a small remuneration for their participation in the study. The subjects' consent was obtained prior to the experiment and care was taken to preserve the anonymity of patients and normal controls.

Experimental assessment

Digit span. A digit span task was used to assess the general capacity of WM. In this task, subjects recalled random sequences of digits drawn from the numbers 1–9. The examiner read aloud a series of digits from the screen of a Macintosh SE hidden from the subjects' view. The digits were presented at a rate of one item per second. Immediately after presentation of a sequence, subjects were required to repeat the sequence orally in the appropriate order. Four trials of sequences of two items each were presented first. If the subject reproduced at least two of the four sequences correctly four sequences of one item longer were presented. The procedure continued until the subject failed to meet the criteria. The longest sequence correctly recalled on at least half of the trials (i.e. two of the four trials) represented the digit span of the subject. One practice trial preceded the task.

Phonological similarity effect. The phonological similarity effect was assessed with separate sequences of similar and dissimilar letters. Two sets of seven letters each were used for constructing the sequences of similar and dissimilar items. The phonologically similar sequences were chosen from the set B, C, D, G, P, T, V whose names rhyme in the French language and the dissimilar sequences from the set of nonrhyming consonants (in French) F, H, L, J, K, R, M. Only letters with a monosyllabic French name were chosen. Each letter set was tested separately. Sequences of items randomly drawn from the appropriate set of letters were presented to the subjects at a rate of 1.5 sec per letter. Five sequences of letters were presented for each length. A practice trial with a short sequence of two items preceded the testing. When it was clear that the subject understood the task, the sequences were presented in increasing number starting with two-letter sequences. The task was to immediately report the sequence in the correct order. Testing was interrupted when the subject failed to correctly report at least three of the five sequences. For this task, the span was the longest sequence recalled on at least half of the trials (i.e. three of the five trials). In the auditory modality, the examiner read aloud the sequences presented on the screen of a Macintosh SE hidden from the subject's view. In the visual modality, the subject silently read each sequence from the screen. Each item was presented individually in capital letters. Oral responses were made for both modes of presentation.

The standard span procedure may, however, not be sufficiently sensitive to allow reliable measurements of differences as a function of the nature of the material presented. Consideration of a series of sequences with a constant length determined by the subject's span has been proposed as a more sensitive method for specifying the nature of a short-term deficit [13, 69]. Therefore, the phonological similarity effect was assessed following the procedure used previously by Belleville and collaborators [13] at the span level of each subject. The span for phonologically dissimilar letters was first determined for each subject as described above. The performance recall for phonologically dissimilar and similar items was compared for sequences in which length corresponded to the subject's span. The correct recall of 5 sequences of phonologically dissimilar letters was thus compared to the correct recall of 5 sequences of phonologically similar letters. The length of these sequences corresponded to the subject's individual span for dissimilar letters. It thus differed from subject to subject. As a result, the absolute number of correctly recalled items is not pertinent here (since subjects are all tested at their span, correct recall should be more or less the same for dissimilar letters). The more relevant information is found in the difference in recall of dissimilar over similar items. This estimation procedure was found to yield significantly reliable effects in the normal young and aged subjects. The same procedure was done separately for each modality. It was also applied to short and long words to measure word length effect.

Word length effect. Two sets of nine words were constructed to generate sequences of short and long words. The short words were taken from a set of monosyllabic words which were: *PAIN, JUPE, CORDE, SAC, CHIEN, TUILE, PLAGE, JAMBE, FLEUR* (in English: BREAD, SKIRT, ROPE, BAG, DOG, TILE, BEACH, LEG, FLOWER), and the long sequences from a set of four-syllable words: *MÉDICAMENT, EXPOSITION, BIBLIOTHÈQUE, ANNIVERSAIRE, ÉDUCATEUR, PHOTOGRAPHIE, DÉCORATION, ADOLESCENT, AUTOMOBILE* (in English: *MEDICATION, EXPOSITION, BOOKCASE, BIRTHDAY, TEACHER, PICTURE, DECORATION, ADOLESCENT, CAR*). Words from each set were matched according to frequency of occurrence [10]. From these two sets, a separate series of randomly selected sequences was created. The span procedure was similar to that described for the phonological similarity task. Here again, both auditory and visual modalities were assessed.

Phonological analysis. Three tasks of phonological analysis were used: one in the auditory modality—a syllable judgement task—and two in the visual modality—a homophony task and a rhyme judgement task.

The phonological analysis of auditory material was evaluated by asking subjects to perform a "same–different" judgement task with orally presented syllables. Forty pairs of syllables, 20 similar and 20 dissimilar, were recorded on a tape. Half of the syllables were of the CV type and half were of the VC type. Of the 20 dissimilar pairs, 10 differed according to the vowel (e.g. BO and BA) and 10 according to the consonant (e.g. BO and RO). Finally, half of the pairs were homophones of real words in French (e.g. *BEAU*) and half of the pairs did not correspond to any known lexical item. Each syllable was spoken by the same female voice in a monotone pitch. The pairs were presented at a rate of about one pair per 3 sec with a 1-sec interval between each syllable. A response was given orally by the subject after each pair.

In the visual homophony judgement task, a stimulus word was visually presented to the subject on a card. This word was underlined and located on the left panel of the card. Four other words were displayed in a squared array on the right panel of the same card. The subject indicated among the four words located to the right the one that sounded the same as the underlined stimulus located on the left. The five items were displayed on the same card to reduce memory load. The underlining and spatial division ensured that the subjects remembered where the stimulus to match was located and what the choices were. The four choices were: a homophone (e.g. in French: *PAIN* for the test stimulus *PIN*), a nonhomophone and orthographically similar word which shared the first phoneme with the test stimulus (e.g. *PAR*), another nonhomophone and orthographically similar word which shared the final portion with the test stimulus (e.g. *LIN*) and a nonhomophone and orthographically dissimilar word (e.g. *GARE*). The items chosen were frequent monosyllabic words and the target was a heterograph of the stimulus. Orthographic regularity was balanced across the stimulus and target. Ten experimental trials followed a practice trial. The examiner used the practice trial to explain what a homophone was and to ensure that the subjects understood the nature of the task.

The procedure used for rhyme judgement was the same as that used in the homophony judgement task except that subjects now had to choose the word that rhymed with the test stimulus (de Partz, unpublished material). Of the four choices, one was a rhyme (e.g. in French: *COURROIE* for the test stimulus *ENDROIT*), one did not rhyme but was orthographically similar to the first two letters of the test stimulus (e.g. *ENNUI*), one did not rhyme but was orthographically similar to the last portion of the test stimulus (e.g. *PORTRAIT*) and one was semantically related (e.g. *LOCAL*). The items were regular bisyllabic and frequent words belonging to the same grammatical class of nouns. Twenty-four experimental trials were presented. Two practice trials were allowed to explain to the subjects what a rhyme was and to ensure that they understood the task.

Adapted Brown–Peterson procedure. The central executive component of WM was examined using a modified version of the classical Brown–Peterson procedure [16, 44, 53]. Three consonants were auditorily presented to the subjects. They had to memorize the trigram while performing either a tapping task or an addition task for a delay varying from 0 to 30 sec (0-10-20-30). The tapping task consisted of tapping repeatedly on the table as rapidly as possible with the left index finger. The examiner monitored the rate of tapping and encouraged the subject to tap regularly by tapping with the subject at the beginning of the delay and any time during the delay if the pace slowed down. The addition task consisted of adding one to a series of random numbers given orally by the examiner (e.g. to 63 the subject should answer 64). The rate of presentation of the numbers depended on the speed at which the subject provided the answer; in general, it was about one every 2 to 3 sec. A control condition with no interference was included. In this condition, subjects were instructed to concentrate on the letters during the delay without repeating them aloud. Immediately after the delay, an auditory signal notified the subjects to produce their response. They were required to write down the three consonants on a response sheet, in the order in which they were presented. If they could not recall one of the consonants, they were asked to leave an empty space where it should be. At the beginning of each interfering condition, three practice trials were given in order to familiarize the subjects with the procedure and to minimize the effect of proactive inhibition [6, 31]. If the subject did not understand the task, the practice trials were repeated. With the DAT patients, it was often necessary to begin by familiarizing them with the interfering task only, before asking them to coordinate it with recall. Testing took place in two different sessions. In each session, subjects were tested on 30 trials, comprising 10 trials for each interference condition at random delays.

Experimental design. Subjects were tested in two sessions of about 90 min each. The first session started with the digit span. The phonological similarity and word length tasks were tested in different sessions with half the subjects completing the auditory condition in the first session and the other half completing the visual condition first. The second session ended with the phonological tasks. The order of presentation of short and long items as well as similar and dissimilar items was varied across subjects according to a Latin square design. The order of presentation of the three interference conditions in the adapted Brown–Peterson task also varied across subjects following a Latin square.

Results

Ten out of the original pool of 20 patients completed all tasks while 10 were tested on a subset. The patients who were not tested on the complete test battery either refused to complete a part of the testing because they were too tired, showed behavioral problems (aggressiveness or crying), or failed to understand the nature of the task. Failure to follow the instructions was particularly frequent in the Brown–Peterson task where 6 of the 20 patients could not alternate between the interference task and the recall. Two patients also failed to understand the notion of rhyme in the rhyme judgement task. Testing was interrupted upon the patient's request or because of obvious emotional problems in the other cases. This occurred in equivalent proportions on the tasks of phonological analysis, and on the Brown–Peterson, while on only one occasion on the span tasks. Consequently, the number of DAT patients tested fluctuates from one task to the other. Note, however, that care was taken to replace patients in the Latin square to maintain proper counterbalancing. The information regarding the number of patients tested in each task is provided in the corresponding tables and figures.

Digit span

All patients were tested on the digit span task. Group differences on the digit span were assessed using an analysis of variance (ANOVA) with Group (DAT, normal, young) as the between-subjects factor. A significant Group effect was found on the digit span (F (2, 41) = 6.61, $P < 0.01$). The average span sizes were 6.33, 6.08, and 4.85 for young subjects, normal aged, controls, and DAT patients, respectively. *Post hoc* tests revealed that the DAT subjects were significantly impaired compared to the group of normal elderlies ($P < 0.05$) but that the aged and young subjects did not differ significantly.

Phonological similarity effect

Figure 1 represents the correct recall of phonologically similar and dissimilar items in the three groups under both modes of presentation. The lengths of the sequences were matched to individual spans. The number of correct sequences was analyzed using a three-way analysis of variance (ANOVA) with Group (DAT, aged, young) as a between-subjects factor, and Similarity (dissimilar, similar) and Modality (auditory, visual) as within-subjects factors. The analysis revealed a significant main effect of Similarity (F (1, 40) = 76.35, $P < 0.001$), with dissimilar letters being recalled better than similar ones. There was also a main Group effect (F (2, 40) = 3.80, $P < 0.05$). These main effects were qualified by a significant Group by Modality interaction (F (2, 40) = 4.79, $P < 0.05$) showing that only aged subjects were affected by the modality of presentation (F (1, 40) = 5.60, $P < 0.01$). More importantly, a Group by Similarity interaction also reached significance (F (1, 40) = 5.69, $P < 0.01$), showing that a larger effect of phonological similarity was found in the young (F (1, 40) = 14.90, $P < 0.001$) and the aged subjects (F (1, 40) = 21.12, $P < 0.001$) than in DAT patients in whom the phonological similarity effect just missed significance (F (1, 40) = 3.88, $P = 0.056$). The seemingly paradoxical superior performance of the DAT subjects on similar items relates to the fact that the stimuli were matched to each individual's span and to the smaller effect of phonological similarity on these subjects. Finally, there was also an interaction between Modality and Similarity (F (1, 40) = 5.05, $P < 0.05$), indicating that similarity effects were larger with auditory (F (1, 40) = 89.83, $P < 0.001$) than with visual (F (1, 40) = 16.50, $P < 0.001$) presentations. There was no three-way interaction ($F < 1$).

Word length effect

Figure 2 shows the number of short and long words correctly recalled in both visual and auditory modalities of presentation. These scores were analyzed using a three-way analysis of variance (ANOVA) with Group (DAT, aged, young) as a between-subjects factor, and Length (short, long) and Modality (auditory, visual) as within-subjects factors. The analysis revealed a significant main effect of Length (F(1, 41) = 133.32, $P < 0.001$) with short words affording better recall than long words. There was no other significant effect ($F < 1$ in all cases).

Phonological analysis

The number of correct responses in the auditory syllable discrimination, the visual homophony judgement, and the visual rhyme judgement task is shown in Table 1. These scores were analyzed separately for each task by ANOVA with Group (DAT, aged, young) as the between-subjects factor.

In the auditory syllable discrimination task there was a significant main Group effect (F (2, 34) = 4.75, $P < 0.05$). DAT subjects were impaired relative to normal-aged subjects (with Tukey's comparison, $P < 0.01$) but aged and young subjects did not differ from one another. The Group effect reached significance (F (2, 33) = 5.97, $P < 0.01$) on the rhyming task, while

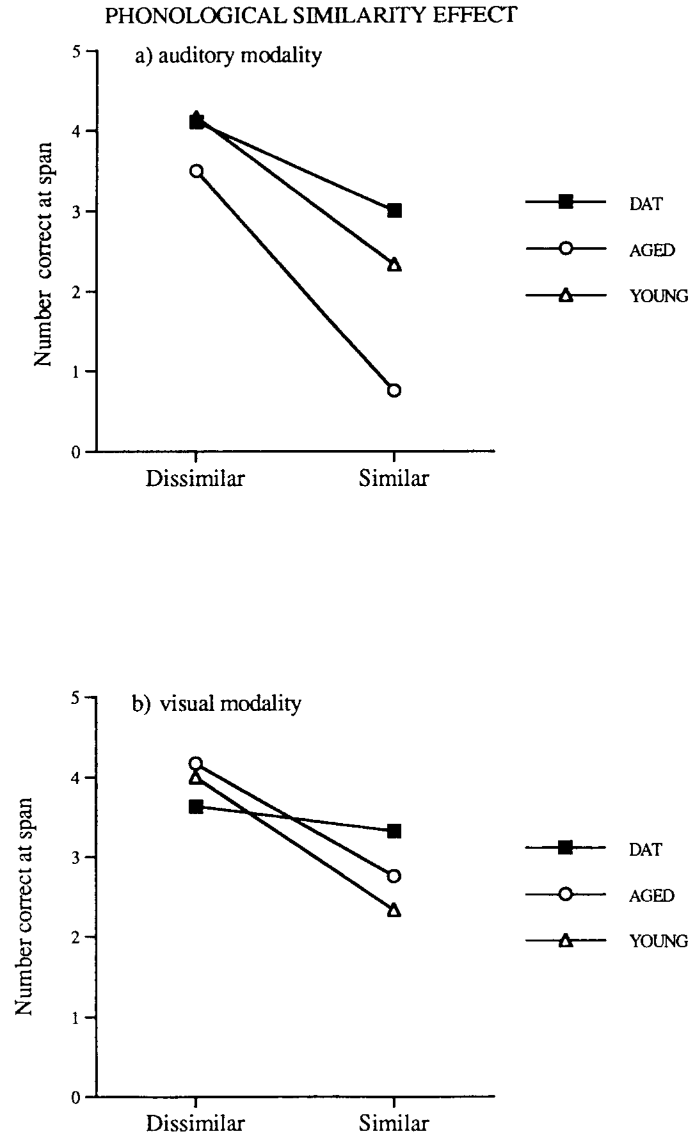

Fig. 1. Number of dissimilar and similar letters recalled at span in the (a) auditory and (b) visual modalities, for young subjects ($n=12$), normal elderlies ($n=12$), and DAT patients ($n=19$).

approaching significance (F (2, 34) = 2.93, $P<0.07$) on the homophony task. DAT patients were impaired relative to young normal subjects ($P<0.01$) but not relative to normal elderlies. Normal aged and young subjects did not differ significantly.

Adapted Brown–Peterson procedure

Data for the adapted Brown–Peterson procedure is presented in Fig. 3. The data analysis included three factors, one between-subjects factor, Group (DAT, aged, young), and two within-subjects factors, Delay (0, 10, 20, 30 sec) and Interference task (none, tapping, addition). The ANOVA revealed main effects of Group, Delay, and Interference. All interactions were significant including the three-way interaction (F (12, 198) = 3.07, $P<0.001$).

In order to interpret the three-way interaction, the data was analyzed separately for each Interference condition. In the "no interference condition," the analysis revealed a main effect of Group (F (2, 33) = 18.58, $P<0.001$) and Delay (F (3, 99) = 2.94, $P<0.05$), as well as a significant interaction between these two factors (F (6, 99) = 2.60, $P<0.05$). The interaction may be explained by a decline in performance with increasing delay (F (3, 99) = 7.54, $P<0.001$) observed only in DAT patients, and not in the aged and young normal subjects ($F<1$). In the "tapping condition", there was also a significant Group effect (F (2, 33) = 12.345, $P<0.001$) related to the lower recall level of DAT patients compared to normal subjects. The effect of Delay (F (3, 99) = 2.44, $P<0.07$) as well as the interaction between Delay and Group (F (6, 99) = 2.07, $P<0.07$) only approached significance. Finally, the analysis of the data in the addition condition yielded a

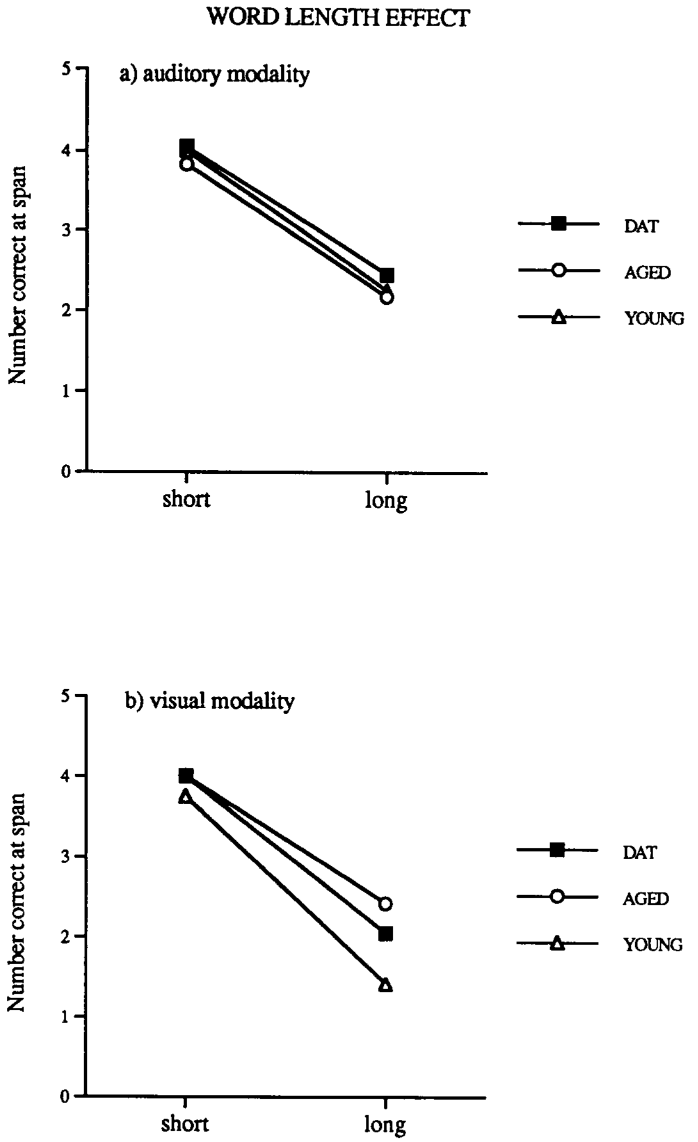

Fig. 2. Number of short and long words recalled at span in the (a) auditory and (b) visual modalities, for young subjects ($n=12$), normal elderlies ($n=12$), and DAT patients ($n=20$).

significant Group effect ($F\,(2, 33)=26.99$, $P<0.001$) and a Delay effect ($F\,(3, 99)=75.645$, $P<0.001$) as well as an interaction between these two factors ($F\,(6, 99)=7.751$, $P<0.001$). The interaction is explained by a larger effect of the delay in the DAT patients ($F\,(3, 99)=66.38$, $P<0.001$) than in the young and aged subjects where delay was also found to significantly depress performance ($F\,(3, 99)=14.09$, $P<0.001$; $F\,(3.\ 99)=10.67$, $P<0.001$ for the young and aged, respectively) but to a lesser degree.

Examination of individual patterns

Individual profiles were examined to assess whether the averaged group pattern described above persists at

Table 1. Mean performance of young subjects, aged subjects, and DAT patients on the tasks of phonological analysis (standard deviation in parentheses)

	n	Auditory syllable discrimination (maximum score: 40)	Homophony judgement (maximum score: 10)	Rhyme judgement (maximum score: 24)
Young controls	12	37.83 (3.48)	10 (0)	23.92 (0.29)
Aged controls	12	38.33 (1.96)	9.92 (0.28)	22.25 (1.76)
DAT patients	13*	34.36 (4.33)	9.62 (0.65)	20.25 (4.13)

*Only 12 DAT patients were tested on the rhyme judgement task.

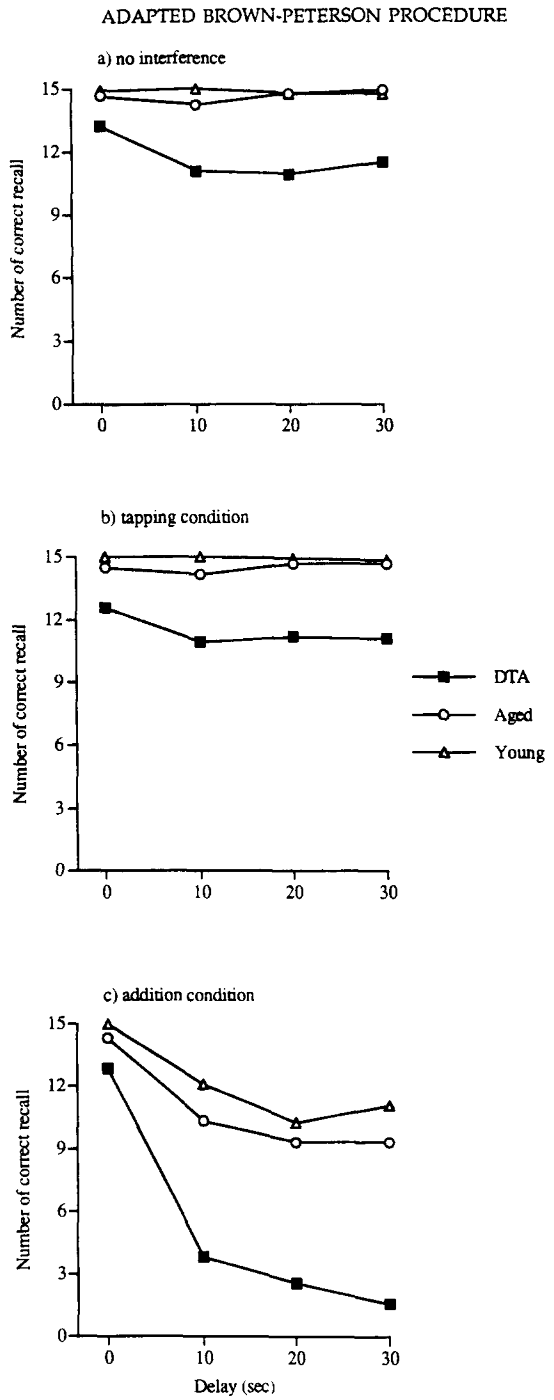

Fig. 3. Number of items recalled with the adapted Brown–Peterson procedure in the (a) no interference, (b) tapping interference, and (c) addition interference, for young subjects ($n = 12$), normal elderlies ($n = 12$), and DAT patients ($n = 12$).

the individual level. This is an important issue due to the heterogeneity in the profiles of cognitive impairments that have been reported in DAT patients [37, 38, 56, 59]. As a result, the pattern of impairment exhibited by each DAT patient was examined with respect to the effects predicted by an intact WM.

The presence of both the phonological similarity effect and the word length effect in the two modes of presentation were used to assess the efficacy of the phonological storage and subvocal rehearsal procedure. All normal subjects showed the expected effects on at least three of the four measures and there was no difference between aged and young subjects regarding the distribution of normal effects. Thus, the presence of the predicted effects in at least three conditions was required for the performance to be considered normal. Furthermore, to be considered as indicative of an impairment, the pattern of performance observed in a given patient had to be interpretable according to a deficit at the level of a particular component within working memory. For example, in the visual modality, access to the phonological short-term store requires the use of the rehearsal procedure [22, 34, 48], while this is not the case in the auditory modality [7]. Thus, impairment of the rehearsal procedure should hinder the observation of a word length effect and of a phonological similarity effect in the visual modality. For the phonological tasks (syllable discrimination, rhyme judgement, and homophony judgement), the performance level of a given DAT patient was considered defective when his/her score was below the lowest score of the aged control subjects. Finally, two scores were determined for the adapted Brown–Peterson procedure: (1) the proportion of loss in the delayed recalls between the tapping and the no interference conditions (i.e. [tapping 10 sec + tapping 20 sec + tapping 30 sec] divided by [no int. 10 sec + no int. 20 sec + no int. 30 sec]), and (2) the proportion of loss in the delayed recalls between the addition and the no interference conditions (i.e. [addition 10 sec + addition 20 sec + addition 30 sec] divided by [no int. 10 sec + no int. 20 sec + no int. 30 sec]). Subjects with a score below that of the worst aged control on any of the two measures were considered impaired on that task.

The analysis of the individual profiles as described above was done using the most severe criteria. Indeed, the significant group effect found in some of our tasks (for example, the phonological ones) can be explained by a displacement of the entire distribution of scores in DAT patients. If this is the case, the best DAT patients may still be better than the worst control. However, the analysis of individual cases, as was done here, neglected these patients and considered them as normal. It is therefore likely that actual impairments were overlooked in some of the patients. Nonetheless, this procedure is interesting because it is equivalent to what is usually done in single neuropsychological case analysis.

Since 10 patients completed all tasks, it was possible to compare the functioning of all components of WM in these patients (see summary in Table 2). Three of these patients (P1, P2, and P3) were impaired only on the adapted Brown–Peterson procedure, and thus probably have a deficit limited to the central executive. Five other patients exhibited anomalies in phonological tasks in addition to a marked deficit on the adapted Brown–Peterson procedure. One of these patients failed on the auditory syllable discrimination test (P4). The second

Table 2. Summary table of individual profiles in DAT patients*

Subject	Reisberg	Adapted Brown–Peterson	Phonological similarity effect	Word length effect	Phonological tasks
P1	3	–	+	+	+
P2	3	–	+	+	+
P3	3	–	+	+	+
P4	4	–	+	+	–
P5	4	–	+	+	–
P6	4	–	–	+	–
P7	4	–	–	+	+
P8	3	–	–/+	–/+	+
P9	3	+	+	+	+
P10	3	+	+	+	+

*The sign – indicates a deficit, + indicates a preservation, and –/+ indicates partial impairment.

showed particularly low levels of performance on both the visual and auditory phonological tasks (P5). A third patient (P6) exhibited no phonological similarity effects in either modality, suggesting that information was not retained under that code. Furthermore, he performed poorly on the task of rhyme judgement. The fourth of these patients also failed to show the usual phonological similarity effect in each modality but performed in the normal range otherwise (P7). The fifth patient (P8) showed a very particular pattern of performance: the phonological similarity effect was present in the auditory but not in the visual modality while the reverse was true for the word length effect (being present in the visual but not auditory modality). This pattern of performance is compatible with a normally functioning articulatory rehearsal procedure and phonological store, since the effects are present with the use of material that has direct access to these components (namely, auditory for the phonological store and visual for the word length effect). However, it may be suggested that a disconnection between the two components is responsible for the pattern of results observed here. The last two patients (P9, P10) were entirely normal, showing no evidence of phonological or central executive deficiencies.

In summary, analysis of the individual performance patterns did not indicate a large heterogeneity at the level of the central executive, since most patients (8 out of 10) had deficiencies of this component. However, there was some variability with respect to the pattern of phonological loop impairment since five of the 10 patients showed a dysfunction at the level of this component. The pattern observed is apparently not directly related to the evolution of the disease. Indeed, all these patients were at the early stage of the disease, scoring at stage 3 or 4 on the Reisberg scale. Finally, it is important to note that such heterogeneity of performance was not observed in normal subjects (young or elderly).

Discussion

The present study examined the effect that DAT has on the functioning of WM components in comparison to normal aging. The results showed that DAT patients had marked difficulties in performing the adapted Brown–Peterson task, which were found to be related to the increasing demand of the task. This finding is congruent with a number of previous studies showing that DAT patients are particularly impaired on demanding tasks, which argues for a deficit at the level of the central executive [8, 9, 44]. However, other components were also affected in DAT, particularly at the phonological processing level. These latter results suggest the existence of multiple deficits in the WM of DAT patients. Accordingly, DAT patients do differ both qualitatively and quantitatively from normal aging. In this section, each of these results will be discussed.

The presence of phonological impairments in some of our DAT patients is not entirely consistent with the existing literature. For example, this result differs from Morris's study [43] which reported normal phonological similarity effects and normal word length effects in his group of patients. One possible account for this discrepancy is that the disease in Morris's patients was simply less severe than in this group of patients. The central executive would thus be the first component to be affected by the disease, and as the affliction progresses, the slave systems of WM would gradually become impaired. Some of our data is consistent with this interpretation as all patients with phonological loop deficits showed an accompanying central executive dysfunction. However, if this explanation is accurate, there should be a straightforward relationship between the stage at which subjects are tested and the degree of their phonological impairment. We have not found such a clear relation here since all subjects were at the very early stage of the disease. This question is worthy of some further investigation and we are currently following some of these patients longitudinally which should help clarify this issue. Another account for the discrepancy between Morris's results and ours may relate to the dependent variable utilized to assess the effects. Indeed, Morris measured the phonological and word length effects by using span size while we used the number of correct recall at span. It is possible that the kind of dependent variable used here was more specific than that used by Morris (see Waters and collaborators [69] for a discussion of this methodological aspect). Thus, in Morris's study different scores on a particular sequence length (for example, a performance of 1/3, 2/3, and 3/3 trials correct recall at length 5 followed by 0/3 trials correct recall at length 6) yielded the same span size (in this example, 5). In our study, this difference is considered in the analysis. This might have been sufficient to yield a larger effect in the group of normal subjects which would result in an interaction. The present results are congruent with Miller's study [42] that did observe a smaller phonological similarity effect in DAT patients.

A related outcome obtained in the present study was the observation that some DAT subjects were also impaired in phonological analysis tasks, whether auditory or visual. The rhyme judgement, homophony judgement, and syllable discrimination task are not memory tasks as such but probably tap on components that are involved in the retention of phonologically-based material. A deficit in these analysis components may thus be responsible for the general defect in verbal span and particularly for the absence of a phonological similarity effect. However, examination of single cases does not reveal any systematic relationship between a deficit in phonological analysis tasks and the absence of a phonological similarity effect in span tasks. While some patients show a deficit on both tasks, others have impaired performance on the phonological analysis tasks only.

Similarly, the observation of a phonological defect in some DAT patients may also have contributed to their impairment on the adapted Brown–Peterson task. Indeed, the Brown–Peterson task is not a pure measure of the attentional resources since it also assessed the strength of the trace in the phonological store (for a discussion of this issue, see [33]). A weak phonological trace would be most damaging to performance in the Brown–Peterson task when subjects are prevented from rehearsing the letters [62]. Such a condition corresponds to the calculation interference task, which was also considered as the most demanding condition in terms of attentional resources. In other words, the lower recall observed in DAT patients in the demanding condition of the Brown–Peterson procedure may simply reflect a more rapid decay or a weaker trace in the phonological storage system. Since the delay functions observed in aged and DAT patients are more or less parallel after the first 10-sec delay, the most likely interpretation of this defect would be related to a defective encoding/retrieval of phonological information in that store rather than to a more rapid decay [19, 32, 65]. However, explaining DAT patients' deficits in WM in terms of a phonological defect cannot be the sole account of their depressed performance. First, deficits have been described in divided attention conditions that did not prevent rehearsal from occurring [8, 9]. Second, there is a significant portion of our patients who showed an impairment on the Brown–Peterson task in spite of a normal phonological storage system. Only an impairment of the attentional component may explain this performance pattern.

Hulme and collaborators [27] have recently concluded that defective articulatory rehearsal can be demonstrated in DAT patients. They reported that the rate of articulation was slowed in DAT and that it correlated with their span for words of increasing length. The present study did not directly assess the speed of rehearsal. It is thus possible that while still functioning, articulatory rehearsal is slowed in DAT. Thus, there is clearly accumulating evidence for an impaired phonological loop in the DAT population. These results are not compatible with the prevalent view in which the WM deficit in DAT patients is isolated to the central executive component.

The present study converges with previous studies in replicating an attentional defect of WM in DAT patients but differs by documenting an additional phonological deficit in at least a subgroup of DAT patients. It is worth emphasizing that up to 80% of DAT patients did manifest a deficit of the central executive, as assessed by the Brown–Peterson procedure. Half of all DAT patients showed, however, both a central executive and phonological loop dysfunction. The latter result indicates the existence of multiple deficits in many DAT patients. The finding of an additional phonological loop defect in a large subgroup of DAT patients allows for the differentiation of normal from pathological aging in WM as the phonological loop was found to be intact in normal aged subjects.

As mentioned in the Introduction, some authors have suggested that elderly people are impaired at the level of the central executive, like DAT subjects, albeit less severely. Yet, in line with other studies [54, 64], we did not observe any defect at the level of the central executive in aged people when compared to young subjects on the basis of their performance on the Brown–Peterson task. This may result from the fact that the resource defect of normal aged individuals is relatively small. The Brown–Peterson task may lack the sensitivity necessary to detect such a minor resource deficiency. That aged subjects may only show minor impairment of the central executive is congruent with the literature. Some studies have observed a detrimental effect of normal aging on divided attention paradigms but others have failed to detect any effect or have reported only minor ones (see [26] for a review).

In conclusion, the increased sensitivity of DAT patients to task demands, such as those manipulated in the adapted Brown–Peterson task, coupled with a defect of the phonological loop system, argues against an explanation of aging and DAT as part of the same continuum. Furthermore, there is evidence that the DAT population is heterogeneous with respect to the extent of phonological loop impairment. This is of major significance as it shows that avering the performance of these patients may lead to erroneous conclusions with regard to their WM impairment.

Acknowledgements—This research was supported by a Grant from the Medical Research Council of Canada (MRC) and Fond de la Recherche en Santé du Québec (FRSQ) to Isabelle Peretz and Sylvie Belleville, by a Chercheur-Boursier fellowship from the FRSQ to Sylvie Belleville, and by a studentship from the Société d'Alzheimer to Dominique Malenfant. The authors would like to thank Hélène Pineau, Arlette Poissant and Sylvian Gaudreau for testing assistantship, Jean Chatelois for computer implementation of the experimental tasks, the clinical neuropsychologists of the Centre hospitalier Côte-des-Neiges for referring some of the patients. Thanks to Ronald Dixon, Elizabeth Ohashi, as well as two anonymous reviewers for their comments on the text.

References

1. Allport, D. A. Auditory–verbal short-term memory and conduction aphasia. In *Attention and Performance*, H. Bouma and D. G. Bouwhuis (Editors), Vol. 10, pp. 313–325. Erlbaum, Hillsdale, 1983.
2. Baddeley, A. D. Short-term memory for word sequences as a function of acoustic, semantic and formal similarity. *Q. J. Exp. Psychol.* **18**, 362–365, 1966.
3. Baddeley, A. D. *Working Memory.* Oxford University Press, Oxford, 1986.
4. Baddeley, A. D. Working memory. *Science* **255**, 556–559, 1992.
5. Baddeley, A. D. and Hitch, G. J. Working memory. In *The Psychology of Learning and Motivation*, G. H. Bower (Editor), Vol. VIII, pp. 47–90. Academic Press, New York, 1974.
6. Baddeley, A. D. and Scott, D. Short-term forgetting in the absence of proactive inhibition. *Q. J. Exp. Psychol.* **23**, 275–283, 1971.
7. Baddeley, A. D., Thomson, N. and Buchanan, M. Word length and the structure of short-term memory. *J. Verb. Learn. Verb. Behav.* **14**, 575–589, 1975.
8. Baddeley, A. D., Logie, R. H., Bressi, S., Della Sala, S. and Spinnler, H. Dementia and working memory. *Q. J. Exp. Psychol.* **38A**, 603–618, 1986.
9. Baddeley, A. D., Bressi, S., Della Sala, S., Logie, R. and Spinnler, H. The decline of working memory in Alzheimer's disease. *Brain* **114**, 2521–2542, 1991.
10. Baudot, J. *Fréquence d'Utilisation des mots en français écrit contemporain.* Presses de l'Université de Montréal, Montréal,1992.
11. Becker, J. T. Working memory and secondary memory deficits in Alzheimer's disease. *J. Clin. Exp. Neuropsychol.* **10**, 739–753, 1988.
12. Belleville, S., Peretz, I. and Malenfant, D. Examen de la mémoire de travail chez un cas d'aphasie progressive. *Rev. Neuropsychol.* **1**, 99–117, 1991.
13. Belleville, S., Peretz, I. and Arguin, M. Contribution of articulatory rehearsal to short-term memory: Evidence from a case of selective disruption. *Brain Lang.* **43**, 713–746, 1992.
14. Belleville, S., Malenfant, D., Peretz, I. and Chatelois, J. The attentional component of working memory in aging (Trouble de la composante attentionnelle de la mémoire de travail dans le vieillissement normal). *Int. J. Psychol.* **27**, 390, 1992.
15. Belleville, S., Crépeau, F., Caza, N. and Rouleau, N. La mémoire de travail dans la démence de type Alzheimer. In *Neuropsychologie clinique des démences. Évaluations et prises en charge*, A. Agniel and F. Eustache (Editors). Éditions Solal, Marseille, 1995.
16. Brown, J. Some tests of the decay theory of immediate memory. *Q. J. Exp. Psychol.* **10**, 12–21, 1958.
17. Caplan, D., Rochon, E. and Waters, G. Articulatory and phonological determinants of word length effects in span tasks. *Q. J. Exp. Psychol.* **45**, 177–192, 1992.
18. Conrad, R. and Hull, A. J. Information, acoustic confusion and memory span. *Br. J. Psychol.* **55**, 429–432, 1964.
19. Corkin, S. Some relationships between global amnesias and the memory impairments in Alzheimer's disease. In *Alzheimer's Disease: A Report of Progress in Research*, S. Corkin, K. L. Davies and J. H. Growdon (Editors), Vol. 19. Raven Press, New York, 1982.
20. Cowan, N., Day, L., Saults, J. S., Keller, T. A., Johnson, T. and Flores, L. The role of verbal output time in the effects of word length on immediate memory. *J. Mem. Lang.* **31**, 1–17, 1992.
21. Dannenbaum, S. E., Parkinson, S. R. and Inman, V. W. Short-term forgetting: Comparisons between patients with dementia of the Alzheimer type, depressed, and normal elderly. *Cognit. Neuropsychol.* **5**, 213–233, 1988.
22. Estes, W. K. Phonemic coding and rehearsal in short-term memory. *J. Verb. Learn. Verb. Behav.* **12**, 360–372, 1973.
23. Flicker, C., Ferris, S. H., Crook, T., Bartus, R. T. and Reisberg, B. Cognitive decline in advanced age: Future directions for the psychometric differentiation of normal and pathological age changes in cognitive function. *Dev. Neuropsychol.* **2**, 309–322, 1986.
24. Foos, P. W. Adult age differences in working memory. *Psychol. Aging* **4**, 500–503, 1989.
25. Gick, M. L., Craik, F. I. M. and Morris, R. G. Task complexity and age differences in working memory. *Mem. Cognit.* **16**, 353–361, 1988.
26. Hartley, A. A. Attention. In *The Handbook of Aging and Cognition*, F. I. M. Craik and T. A. Salthouse (Editors). Erlbaum, Hillsdale, 1992.
27. Hulme, C., Lee, G. and Brown, G. D. A. Short-term memory impairments in Alzheimer-type dementia: Evidence for separable impairments of articulatory rehearsal and long-term memory. *Neuropsychologia* **331**, 161–172, 1993.
28. Joanette, Y., Ska, B., Poissant, A., Belleville, S., Lecours, A. R. and Peretz, I. Development of an "optimal" neuropsychological battery for dementia.

In *Neuropsychological and Functional Assessment of Dementia*, T. Del Ser and J. Pena (Editors). Masson, Barcelona, 1995.

29. Kaszniak, A. W., Garron, D. C. and Fox, J. Differential aspects of ages and cerebral atrophy upon span of immediate recall and paired associates learning in older patients with suspected dementia. *Cortex* **15**, 285–295, 1979.
30. Kemper, T. Neuroanatomical and neuropathological changes in normal aging and in dementia. In *Clinical Neurology of Aging*, M. L. Albert (Editor), pp. 9–52. Oxford University Press, New York, 1984.
31. Keppel, G. and Underwood, B. J. Proactive inhibition in short-term retention of single items. *J. Verb. Learn. Verb. Behav.* **1**, 153–161, 1962.
32. Kopelman, M. D. Rates of forgetting in Alzheimer type dementia and Korsakoff's syndrome. *Neuropsychologia* **23**, 623–638, 1985.
33. Kopelman, M. D. Working memory in the amnesic syndrome and degenerative dementia. *Neuropsychology* **8**, 555–562, 1994.
34. Levy, B. A. Role of the articulation in auditory and visual short-term memory. *J. Verb. Learn. Verb. Behav.* **10**, 123–132, 1971.
35. Light, L. L. and Anderson, P. A. Working memory capacity, age and memory for discourse. *J. Gerontol.* **40**, 737–747, 1985.
36. Lussier, I., Malenfant, D., Peretz, I. and Belleville, S. Caractérisation des troubles de la mémoire dans la démence de type Alzheimer. In *Syndromes Démentiels: Approche Clinique et Neuropsychologique*, M. Habib, Y. Joanette and M. Puel (Editors), pp. 165–187. Masson, Paris, 1991.
37. Mann, U., Mohr, E., Gearing, M. and Chase, T. N. Heterogeneity in Alzheimer's disease: Progression rate segregated by distinct neuropsychological and cerebral metabolic profiles. *J. Neurol. Neurosurg. Psychiatry* **55**, 956–959, 1992.
38. Martin, A. Neuropsychology of Alzheimer's disease: The case for subgroups. In *Modular Deficits in Alzheimer-type Dementia*, M. F. Schwartz (Editor), pp. 143–175. MIT Press, Cambridge, MA, 1990.
39. Martin, A., Brouwers, P., Lalonde, F., Cox, C., Teleska, P. and Fedio, P. Towards a behavioral typology of Alzheimer's patients. *Brain Lang.* **26**, 181–185, 1986.
40. McDowd, J. M. and Craik, F. I. M. The effect of aging and task difficulty in divided attention performance. *J. Exp. Psychol.: Hum. Percep.* **14**, 267–280, 1988.
41. McKhann, G., Drachman, D., Folstein, M., Katzman, R., Proce, D. and Stadlan, E. M. Clinical diagnosis of Alzheimer's disease: Report of the NINCDS–ADRDA work group under the auspices of Health and Human Services Task Force on Alzheimer's Disease. *Neurology* **34**, 939–944, 1984.
42. Miller, E. Efficiency of coding and the short-term memory defect in presenile dementia. *Neuropsychologia* **10**, 133–136, 1972.
43. Morris, R. G. Dementia and the functioning of the articulatory loop system. *Cognit. Neuropsychol.* **1**, 143–157, 1984.
44. Morris, R. G. Short-term forgetting in senile dementia of the Alzheimer's type. *Cognit. Neuropsychol.* **3**, 77–97, 1986.
45. Morris, R. G. and Baddeley, A. D. Primary and working memory functioning in Alzheimer-type dementia. *J. Clin. Exp. Neuropsychol.* **10**, 279–296, 1988.
46. Morris, R. G. and Kopelman, M. D. The memory deficits in Alzheimer-type dementia: A review. *Q. J. Exp. Psychol.* **38A**, 575–602, 1986.
47. Morris, R., Gick, M. L. and Craik, F. I. M. Processing resources and age differences in working memory. *Mem. Cognit.* **16**, 362–366, 1988.
48. Murray, D. J. Articulation and acoustic confusability in short-term memory. *J. Exp. Psychol.* **78**, 679–684, 1968.
49. Nairne, J. S. A feature of immediate memory. *Mem. Cognit.* **18**, 251–269, 1990.
50. Nebes, R. and Madden, D. Different patterns of cognitive slowing produced by Alzheimer's disease and normal aging. *Psychol. Aging* **3**, 102–104, 1988.
51. Norman, D. A. and Shallice, T. Attention to action: Willed and automatic control of behavior. In *Consciousness and Self-Regulation*, R. J. Davidson, G. E. Schwartz and D. Shapiro (Editors), Vol. 4. Plenum Press, New York, 1984.
52. Orsini, A., Trojano, L., Chiacchio, L. and Grossi, D. Immediate memory spans in dementia. *Percept. Mot. Skills* **67**, 267–272, 1988.
53. Peterson, L. R. and Peterson, M. J. Short-term retention of individual verbal items. *J. Exp. Psychol.* **58**, 193–198, 1959.
54. Puckett, J. M. and Lawson, W. M. Absence of adult age differences in forgetting in the Brown–Peterson task. *Acta Psychol.* **72**, 159–175, 1989.
55. Reisberg, B., Ferris, S. H., De Leon, M. J. and Crook, T. The global deterioration scale for assessment of primary degenerative dementia. *Am. J. Psychiatry* **139**, 1136–1139, 1982.
56. Ritchie, K. and Touchon, J. Heterogeneity in senile dementia of the Alzheimer type: Individual differences, progressive deterioration or clinical subtypes? *J. Clin. Epidemiol.* **45**, 1391–1398, 1992.
57. Rochon, E., Caplan, D. and Waters, G. S. Short-term memory processes in patients with apraxia of speech: Implications for the nature and structure of the auditory–verbal short-term memory systems. *J. Neurolinguistics* **5**, 237–264, 1991.
58. Salthouse, T. A., Rogan, J. D. and Prill, K. A. Division of attention: Age differences on a visually presented memory task. *Mem. Cognit.* **12**, 613–620, 1984.
59. Scheltens, P., Vermersch, P. and Leys, D. Hétérogénéité de la maladie d'Alzheimer. *Rev. Neurol.* **149**, 14–25, 1993.
60. Schweickert, R., Guentert, L. and Hersberger, L. Phonological similarity, pronunciation rate, and memory span. *Psychol. Bull.* **1**, 74–77, 1990.
61. Shallice, T. *From Neuropsychology to Mental Structure*. Cambridge University Press, Cambridge, 1988.
62. Shallice, T. and Warrington, E. K. Independent functioning of verbal memory stores: A neuro-

psychological study. *Q. J. Exp. Psychol.* **22**, 261–273, 1970.

63. Spinnler, H., Della Sala, S., Bandera, R. and Baddeley, A. D. Dementia, aging, and the structure of human memory. *Cognit. Neuropsychol.* **5**, 193–211, 1988.
64. Stuss, D. T., Stethem, L. L. and Poirier, C. A. Comparison of three tests of attention and rapid information processing across six age groups. *Clin. Neuropsychologist* **1**, 139–152, 1987.
65. Sullivan, E. V., Corkin, S. and Growdon, J. H. Verbal and nonverbal short-term memory in patients with Alzheimer's disease and in healthy elderly subjects. *Dev. Neuropsychol.* **2**, 387–400, 1986.
66. Vallar, G. and Baddeley, A. D. Fractionation of working memory: Neuropsychological evidence for a phonological short-term store. *J. Verb. Learn. Verb. Behav.* **23**, 151–161, 1984.
67. Vallar, G. and Cappa, S. F. Articulation and verbal short-term memory: Evidence from anarthria. *Cognit. Neuropsychol.* **4**, 55–78, 1987.
68. Van Der Linden, M., Coyette, F. and Seron, X. Selective impairment of the "central executive" component of working memory: A single case study. *Cognit. Neuropsychol.* **9**, 301–326, 1992.
69. Waters, G. S., Rochon, E. and Caplan, D. The role of high-level speech planning in rehearsal: Evidence from patients with apraxia of speech. *J. Mem. Lang.* **31**, 54–73, 1992.
70. Wilson, R., Bacon, L. S., Fox, J. H. and Kasniak, A. W. Primary memory and secondary memory in dementia of Alzheimer type. *J. Clin. Neuropsychol.* **5**, 97–104, 1983.