MEMORY AND AGING: COMPONENTS AND PROCESSES

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SUMMARY

This article provides a critical review of memory and aging. The focus is on the more accepted ternary scheme of memory, i.e. procedural, semantic and episodic, and on processing resources. A review of the literature in these areas, considering the more relevant studies or those with a greater number of subjects, reveals a gradual decrease of performance with age. No single hypothesis, either psychological or physiological, seems to be capable of explaining this decline. However, the hypothesis of a cognitive slowing during aging has an appealing simplicity and offers the chance to integrate the myriad of task-specific explanations that have proliferated in the literature.

INTRODUCTION

Memory is the most important of the cognitive functions, to the point of being considered propaedeutic to all the other functions. Therefore, it is understandable why any alteration or any decrease in its functioning should be viewed with special concern both from a medical and a social standpoint. Thanks to studies on patients with focal lesions, remarkable progress has been made in the comprehension of this function at psychological and neurological level over the last two decades. It is now clear, for example, what role is played by structures such as the hippocampus, dorsomedial thalamic nuclei and mamillar nuclei for the establishment of new memories.

The analysis of the memory problems in physiological and pathological aging offers a new challenge to researchers: to understand what may be the causes of memory decrease when there is no manifest focal modification.

It is known that profound changes occur in the brain morphology with aging and these "normal" age-related changes are often much greater in magnitude than structural brain changes observed in a number of disease states, among which various forms of dementia. At present, none of these alterations can be related to behavioural deficits.

Changes in the memory processes certainly occur with aging. The nature and range of these changes are, nevertheless, far less easily identifiable and describable on the basis of the current theoretical models.

SYMPTOM FREQUENCY

Before describing the specific problem of memory decline, I would like to report some data about the frequency of memory complaints.

In the Gospel Oak study (1) made on 813 subjects, ranged in age between 60 and 98 (mean age = 73.8), subjective memory complaints affect about 25% of the population. A national U.S. survey on more than 14,000 adults aged 55 and over shows: 1) 15% of respondents frequently had difficulty in remembering things; 2) almost 40% indicated that they sometimes had trouble remembering things and 3) 26% said they never had any problem (2).

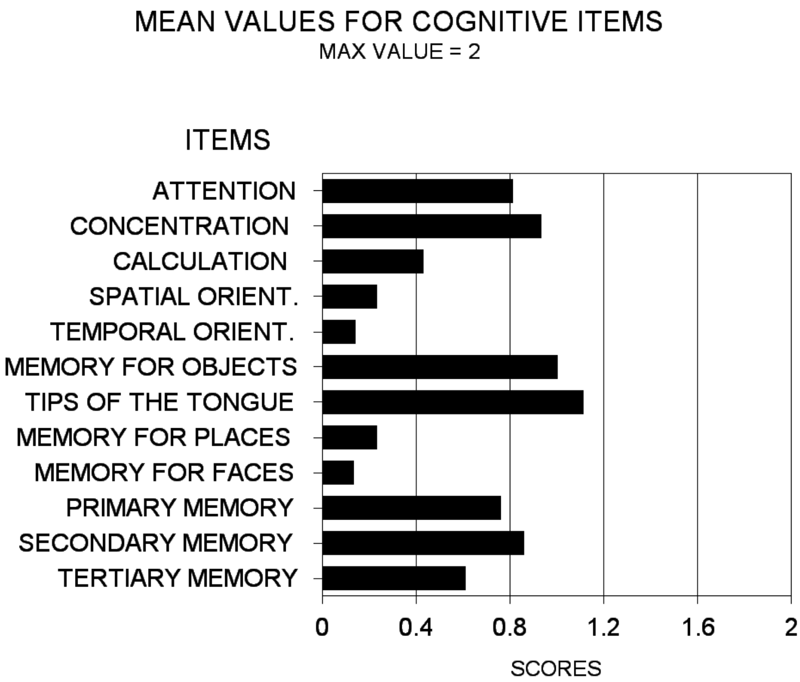
The subjective memory rating, on a 5-point response scale, obtained from a sample of 1,491 subjects by Herzog and Rodgers (3), shows a perceived decrease with age and a significant correlation with the rating both of relatives and of interviewers (Table I).

Table I - Memory rating expressed on a 5-point scale, where 5 stands for no difficulty and 1 for the inability to recall much information (3).

	Age groups			
	20-39	40-59	60-69	>70
Self-rating	4.37	4.17	4.10	3.84
Spouse-rating	4.49	4.40	4.19	4.02
Interviewer-rating	4.58	4.50	4.24	4.10

The main symptoms of memory deficiencies are, among others, "tips of the tongue", "forgetting where you have put something" or "forgetting something you were told yesterday". Fig. 1 summarises the mean values obtained for 12 cognitive items on a 201-sample (mean age = 60.4). Point 2 represents the maximum frequency of symptom.

Fig. 1 -



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MEMORY STRUCTURE

Episodic/semantic memory

Memory is a complex function which depends on the combined activity of several brain areas. Recent evidence of this is reported by Tulving (4) based on data about the cerebral blood flow: the retrieval of information with specific temporal and spatial characteristics (episodic remembering) is accompanied by a comparatively greater activation of the anterior cortical regions, whereas retrieval of semantic knowledge is accompanied by a greater degree of activation in the posterior regions. This result is remarkable as it supports the distinction between semantic and episodic memory (5), and especially because it could explain why a greater episodic memory decline is present in normal aging. Indeed, recent data suggest that normal aging processes might be linked to inefficient frontal lobe functioning (6-8).

Tulving suggests a ternary classificatory scheme of memory, in which each system depends on, and is supported by, the lower system or systems, but possesses unique capabilities not possessed by the lower systems. The three systems are: procedural, semantic and episodic memory. Procedural memory refers to learned connections between stimuli and responses, which are not accessible to consciousness. For example, procedural memory seems to be involved when we are driving or typing. Semantic memory refers to general knowledge of the world which is not linked to a particular temporal-spatial context; it permits the organism to construct mental models of the world. Semantic memory is used when we remember that bananas are a type of fruit. Episodic memory refers to conscious recollection of personally experienced events and their temporal relations. Procedural memory supports semantic memory and semantic memory supports episodic memory. Semantic memory can function independently from episodic memory but not independently from procedural memory. Episodic memory depends on both procedural and semantic memory for its working, although it also possesses its own unique capabilities. The three systems constitute what might be called a monohierarchical arrangement. Much of the support for the three separate systems comes from research on brain-damaged individuals. For example, some amnesic patients fail to remember where or when a fact was learned, though they can remember the fact itself (source amnesia).

Though there is no general agreement about the fact that these types of patients can be described exclusively on the basis of this system, it is nevertheless possible to continue to use this model to explain some memory deficits and to apply it to the problems of aging. For example, the data referring to frontal lobe lesions provide clear evidence that temporal information, one component of episodic memory, is linked with the activity of specific portions in the frontal regions. The frontal cortex allows the accurate temporal order of an event and its relationship with other previous or subsequent events to be remembered (6).

Tulving's model refer, substantially, to three dimensions: time, semantic and consciousness. Each dimension interacts with the others in order to confer different states to our memories. Finally, it seems to me that this model can adequately sum up the various dichotomies suggested by studies on memory and its related disorders. For instance, cognitive decline could progressively involve episodic, semantic and finally procedural memory. In the case of aging, Mitchell (9) mentions a monohierarchical ordering of relative deficits: greatest in episodic, some in semantic, least in procedural.

The study conducted by Mitchell (9) briefly synthesises these results. The work was carried out on 48 young and 48 elderly subjects, who were given different tasks related to procedural memory, semantic memory and episodic memory. The material was made up of figures with high or low codability as defined in the Snodograss and Vanderwart (10) study. Table II reports several measures typical of the three systems.

Table II - The table illustrates some typical tasks of the three-different memory systems.

Procedural
- Naming latencies for repeated vs nonrepeated items
(repetition priming)

Semantic
- Picture-naming latencies
- Picture-naming errors

Episodic
- Free recall
- Recognition

As for procedural and semantic memories, the differences in the conditions analysed are equal for young and elderly subjects, though there are some absolute differences between them, particularly relative to latencies.

On the contrary, in the recall and recognition tasks (Table III) there are large differences between the two groups. As is typical of memory studies, the percentage of recognised stimuli is much higher than in the case of recall. In the present study, the percentages of recognition are more than twofold compared to recall.

Table III - Percentage of pictures recalled as a function of codability, repetition and age groups (9).

	Young	Old
Repetition 1		
- High codability	26	21
- Low codability	27	22
Repetition 2		
- High codability	35	28
- Low codability	44	40

Implicit/explicit memory

Another distinction made in memory studies is between implicit and explicit memory. Implicit memory is involved in those situations where a previous experience influences the following experience, though we are not aware of it. Explicit memory is involved when an intentional or deliberate recollection of facts is required. Examples of implicit memory are repetition priming tasks in which prior exposure to a stimulus increases the probability of responding to that item or to associated items.

In the study by Hultsh, Masson and Small (11), conducted on 584 subjects (19-86 years old), implicit memory was measured through the influence exerted by words previously seen on a stem-completion task. At variance with what is commonly stated, that study showed the clear superiority of the young subjects (19-36 years old), thus suggesting that age differences can be detected also for implicit memory. This result could be particularly relevant to carrying out a more accurate analysis of aging deficits. In the same study, explicit memory was measured, among other things, through a story recall and a word recall task. In Table IV we can observe a decline of memory performance from the youngest group to the oldest and a definitely improved performance for word recall in comparison to story.

Table IV - Correct proportion for two explicit memory tasks as a function of age groups (11).

n=584	Age groups 19-36	55-69	70-89
Story recall	0.428	0.329	0.299
Word recall	0.668	0.614	0.545

Table V - Correct proportion for story recall as a function of age groups and time of recall (modified from 12).

n=106	Age groups Young-old	Old-old
Immediate	0.536	0.470
Delayed	0.491	0.403

A story recall is again used in the study by Luszcz (12). The subjects were divided in two groups: young-old (mean age = 67, n=107) and old-old (mean age = 80, n=58). Recall scores were obtained immediately after presentation and after a 20 min delay. The number of recalled items (see Table V) was a function of the moment when the items of the story were requested and the old-old group was more impaired than the young-old group.

A multiple regression analysis undertaken on the data allows us to specify the weight of age in this task. In the analysis which considers education, physical health, intellectual level, processing speed and age (variables that explain 35% of the variance), age accounts for very little of the variance (0.1%), while intellectual ability explains 10.6% of the variance. This is a typical result in more recent studies (e.g. 13).

ECOLOGICAL APPROACH

The study by Herzog and Rogers (3), quoted above, reports particularly interesting data on recall and recognition. Laboratory studies on aging are often criticised because of the relative artificiality of their conditions. The decline in the elderly subjects may partially be due to this. More ecological tasks, which would be closer to everyday reality, may not reveal the same differences. In the study by Herzog and Rogers, the subjects' memory was assessed on the basis of the ability to recall or to recognise items suggested to them during a general interview. In the recall procedure, subjects were asked to recall six physical and mental functions that they had rated during the interview. In the recognition task subjects were required to recognise 10 questions, which had actually been asked, from 10 questions which had not been asked. Table VI reports the results: we can notice a gradual decline as a function of age. Correlation between age and recall is -0.29 and that of age with recognition is -0.39. A multiple regression analysis shows, also in this study, that the age effect is reduced markedly when other factors such as education, intellectual level and physical health are controlled.

Table VI - Memory performance in four age-groups as a function of recall and recognition (3).

n=1463	Age groups			
	20-39	40-59	60-69	>70
Recall	1.6	1.44	0.77	0.46
Recognition *	5.37	4.39	3.27	2.16

* Hits minus false alarms.

Table VII - Memory performance in five age-groups as a function of set sizes (15).

n=1205	Age groups				
Set size	18-39	40-49	50-59	60-69	>70
4	3.41	2.99	2.85	2.59	1.99
6	3.55	2.83	2.44	1.94	1.53
14	4.89	3.43	2.92	2.33	1.81

A more systematic approach to a naturalistic study of memory is proposed by Crook and his co-authors (e.g. 14). Laboratory-analogues of everyday memory tasks are proposed. The tests include measures of immediate and delayed recall, single- and repeated-trial acquisition, serial and free recall, as well as cued recall and recognition. In one task (15) subjects were asked to recall four, six or 14 names of individuals, who introduced themselves on videotape. Immediate recall, acquisition and delayed retention were examined. Table VII reports age group means for immediate recall. Performance markedly decreases from the younger to the older group, whereas the decline is less evident in the individuals aged 40-60 when set-size 4 and 6 is used, and more evident with set-size 14. It is worth noting the absolute values, which represent the number of reported items, as well as that this number, across different set sizes, is practically constant for all groups, except for the youngest. The delayed recall (40 min later; set size 14) did not alter the aging pattern found in the immediate recall test.

A multiple regression analysis made considering age, education, gender and vocabulary (WAIS) indicated that all variables, except education, were important predictors of memory performance. The non-significance of education, at variance with other studies, is explained by the authors as due to the higher educational level (15.53 years) of the sample. A second multiple regression analysis, carried out by adding the performance of the subjects in other tests of the battery, shows that the reaction-time value is one of the main predictors for memory performance. The importance of mental speed for the age-related decline of memory will be discussed later.

In a second study published by Crook and co-workers (16) data from other tests of the battery are presented. Also in this case multiple regression analysis indicates age and vocabulary as strong predictors. Education influences the subject's performance only when age is partialled out. This effect might depend on the fact that another measure, vocabulary, is included in the analysis and this may cause an overlapping. Another reason could be the group's educational level, which here, too, is high (15 years).

The weight of variables is not the same for all tests. For example, one of the tests of the battery requires the subjects to dial a telephone number (7 digits) read immediately before. Each digit dialled in its correct serial position is given a point. For a group of 1,374 subjects the mean was 6.60 (S.D. 0.56), a very high value if matched with other data on immediate memory. For example, the mean number of recalled names was 3.59 (S.D. 2.64). Even more interesting is the fact that in this test the age variable is not significant, but the vocabulary variable is.

Another ecological test has been used in Read's study (17) which I would like to report as an example of the analysis of verbal and spatial aspects within the same task. The Supermarket Test consists of 16 supermarket items placed on three shelves of a miniature supermarket.

Subjects are required to name and price each item. Three min are given to recall the items, followed by the request to replace all items in their original location in the miniature supermarket. The task was administered to 734 subjects (50-79 years old), subdivided into 3 decades. Table VIII shows that the spatial location recall seems to score higher than the item recall. Unfortunately, Read reported distinct statistical analyses for each task. We should note that the 50-59 group does not differ from the 60-69 group for both tasks. However, the delayed item recall shows significant differences among the three groups.

Table VIII - Memory performance in three age-groups as a function of the type of recall (17).

n=734	Age groups		
	50-59	60-69	70-79
Item recall	10.1	9.76	9.03
Location recall	12.52	12.3	11.1

Digit and spatial span

A study conducted by Orsini et al. (18) considered the performances given by a large number of subjects (1,354) in a spatial span test (Corsi's task) and a digit span test (Wechsler's digits forward). In this case, too, separate analyses were reported; however, their data clearly show a lower performance in spatial recall (see Table IX). A similar finding is reported by Spinnler and Tognoni (19). Moreover, Orsini's study indicates that years of schooling positively influence performance.

Table IX - Memory performance in five age-groups as a function of the type of task (modified from 18).

n=1354	Age groups				
	20-39	40-49	50-59	60-69	>70
Digit	5.47	5.48	5.42	5.43	4.90
Spatial	4.85	4.78	4.76	4.61	4.11

It is very important to analyse the absolute values reported in each individual study, as they give us the opportunity of better understanding the developmental pattern of memory.

According to Lezak (20), normal letter span is 6.7 in the 20's, 6.5 in the 50's, 5.5 in the 60's and 5.4 in the 70's. The mean for a 9-word list should be 5.6 words for 20-29 year-olds and 5.0 for 60-69 year-olds. These values should remain constant across lists of different length. In a my recent study, the different-length lists (from 4 to 9 words) resulted in constant values (see Fig. 2) in the elderly group (mean age 68.9, n=32), whereas a constant increase was present in the younger group (mean age 20.5, n=32), up to an average of 5-6 element items.

Fig. 2 - Memory recall as a function of list length.

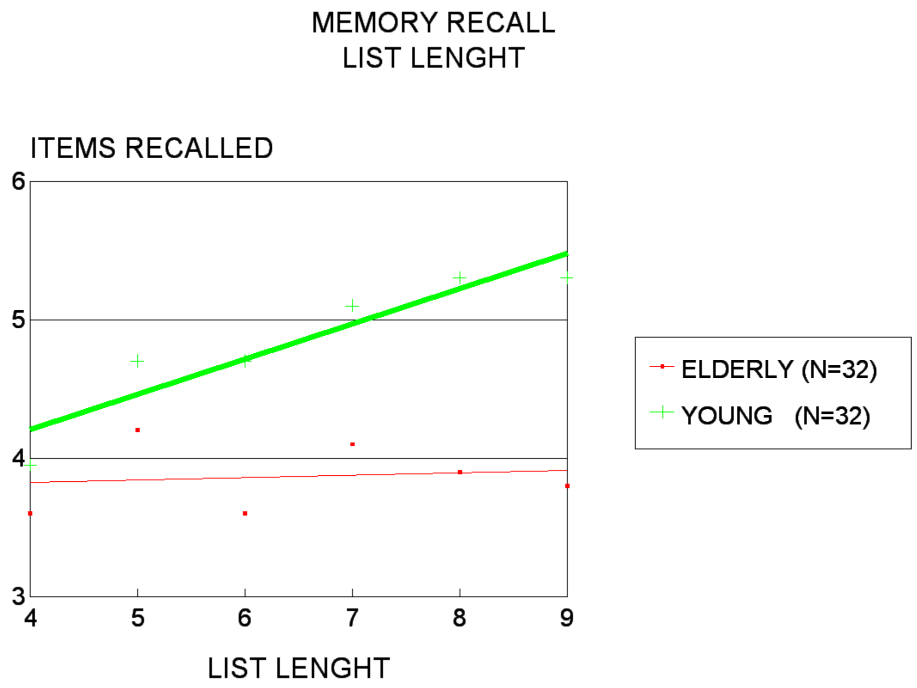

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Table X - The table reports data obtained on digit, word and spatial span by different authors.

Authors	n	Age	Digit span	Word span	Spatial span
Rey, 1964 (21)	15	70-90		3.7	
	15	70-88		4.0	
De Renzi et al., 1977 (22)	100	21-70		4.81	
Corkin, 1982 (23)	14		7.1		5.5
Orsini et al., 1986 (18)	238	20-29	5.53		4.91
	146	60-69	5.43		4.61
	268	70-79	4.84		4.18
	125	80-99	5.04		3.97
Spinnler and Tognoni, 1987 (19)	321	40-90		4.22	4.69
	43	60-64		4.44	4.98
	42	65-69		4.18	4.77
	48	70-74		4.12	4.35
	37	75-79		3.73	4.24
	47	80-90		3.68	4.16
Orsini et al., 1990 (24)	30	63.7	4.8	4.0	4.3
Sgaramella and Bisiacchi, 1990 (25)		70.2		3.55	4.2
Spinnler et al., 1988 (26)	42	18-49		4.67	5.14
	58	50-84		4.33	4.74
Salmaso and Viola, 1989 (27)	48	17-88		4.23	3.42
	16	17-27		5.06	4.18
	16	57-82/IQ+		4.0	3.81
	16	57-88/IQ-		3.6	2.25

The constancy of memory span is illustrated in Table X, which presents the values obtained for digit span, word span and spatial span in different studies. It is worth noting the strong constancy of these values, which are well in line with the famous 7±2 of George Miller (28).

Orienting and criterial variables

Besides variables relative to the subjects or the materials used, there are other variables which are important in the case of mnesic performances and that are often neglected. They are defined by Jenkins (29) as orienting and criterial: they can alter the memory task, thus making it more easy or more complicated. Therefore, these variables do not modify either the materials or the subjects under study. In many memory studies, these variables are intentionally manipulated, whereas many other research studies on memory and aging simply ignore them. Memory performances vary considerably with the specific task characteristics, which may or may not determine age-based differences. These characteristics must be taken into account to understand the size of the differences between the groups or the nature of these differences. I will illustrate this point with a few significant examples.

The length of the words used in a task modifies (Table XI) the absolute values obtained for the span (30).

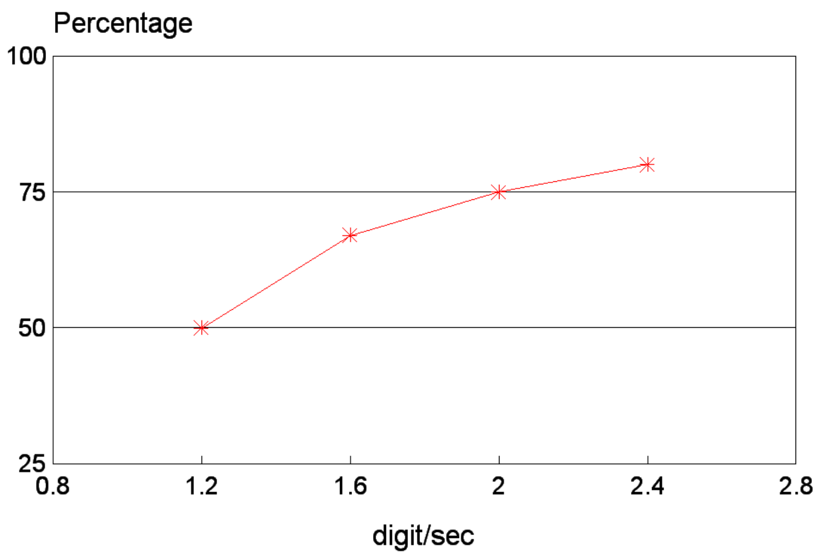
Table XI - Memory performance in three age-groups as a function of the word-length (30).

n=82	Age groups		
	17-23	60-74	75-94
One-syllable	4.6	3.8	3.5
Two-syllable	4.2	3.6	3.2
Three-syllable	3.9	3.0	2.4

The presentation rate also influences memory performance. For instance, the percentage of correct responses increases from 51% to 82% (see Fig. 3) with a slower presentation rate (31). Similarly, Craik and Rabinowitz (32) reported an increase in performance when moving from a 5-sec presentation rate to a self-paced presentation (median 20 sec per word); the increase is 19% for an elderly group and 34% for a group of young people. Finally, a my recent work (27) shows a significant 4% increase from 2- to 10-sec presentation rate, but this effect does not interact with age.

Fig. 3 - Percentage of correct responses as a function of presentation rate (31).

PRESENTATION RATE
From Gronwall (1977)



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In the name-recall task (see Table VII) of the Crook and Larrabee battery (14) the subject is not required to free-recall, but rather to provide a cued-recall, as the face previously associated to a specific name is shown to him. Consequently, this is a task which is different from the simple immediate recall. Even the telephone-number task is very different from simple recall: the subjects see the numbers on a screen that they are requested to read. Then they dial the number on a standard push-button phone. Therefore, the task is carried out through a twofold modality (visual and acoustic), and the recall is performed in yet another modality. This might account for the high means scored in this test.

There are reasons to believe that differences may be due to the modalities of presentation (e.g. 33). Performance should be facilitated by acoustic presentation because of the more immediate use of the verbal code, a code which might elicit grouping or chunking of numbers. In the study by West and Crook (34), series of 7 or 10 numbers were used in 4 different test conditions, as illustrated in Table XII. All conditions provided for an acoustic presentation. The study was conducted on two age groups (116 + 116 subjects), 18-30 and 60-80.

Table XII - Different conditions explored for immediate number recall (34).

Condition	Description
N	Number series
T	Numbers designed as telephone numbers
TC	Telephone numbers chunked during presentation
TCD	Telephone numbers chunked and dialled (at recall)

Older people are significantly worse than younger; this effect (Table XIII) changes across conditions for 7-digit numbers, but not for 10-digit numbers. Both groups performed better in TC and TCD conditions with 10-digit numbers, whereas with 7-digit numbers the effect was present only in the elderly group. The longer the series of numbers to be remembered, the more the chunked presentations helped memory.

Table XIII - Mean scores obtained by younger and older subjects in the four conditions (34).

	Younger	Older	Younger	Older
Condition *	7-Digit		10-Digit	
N	6.2	4.8	4.6	3.4
T	6.6	5.4	5.9	3.7
TC	6.7	6.6	7.3	5.5
TCD	6.7	6.4	6.9	4.4

* See Table XII for explanation of conditions.

A more orderly approach to the orienting and criterial variables indicated by Jenkins (29) is the study conducted by Craik, Byrd and Swanson (35). In that study, free and cued recall are studied together with free and cued presentations. Lists of 10 common nouns are presented to 4 groups of subjects in a word recall task. Results (see Table XIV) show an increase in the performance from free-free condition to cued-cued one. This effect applies to all groups, but it is more noticeable in the group of elderly subjects with the worst performance

(Old3). The drop in performance from the young group to the Old3 group is greater in the free-free condition (3.6 words) than in the cued-cued condition (2.3 words). This means that the group with poorer performance benefits more than other groups from the cued-cued condition.

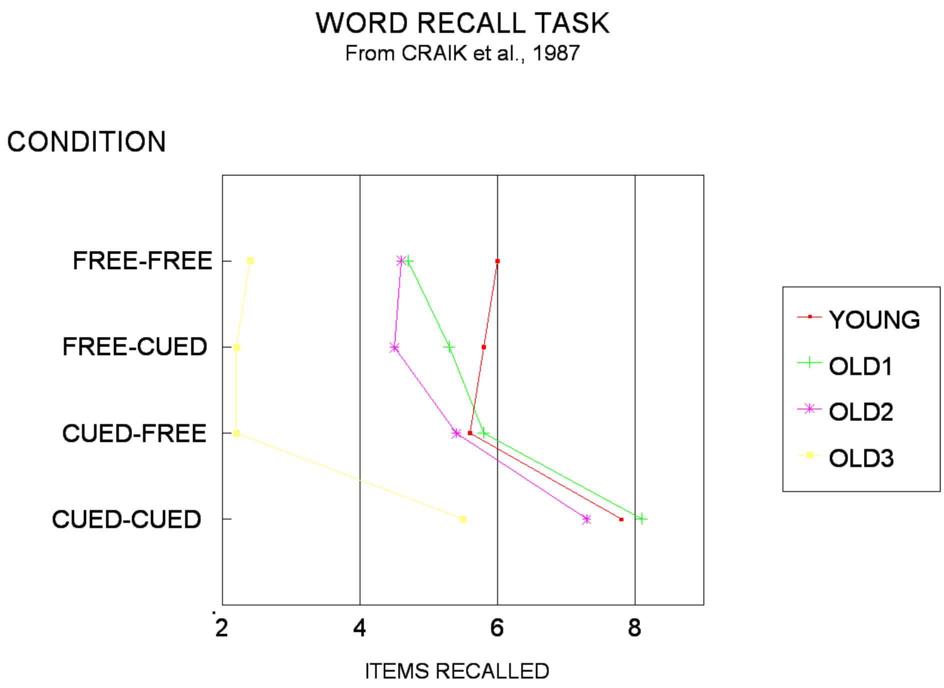
Table XIV - Mean scores obtained in a word recall task across four conditions (35).

Condition Presentation-Recall	Young	Old1	Old2	Old3
Free-Free	6.0	4.7	4.6	2.4
Free-Cued	5.8	5.3	4.5	2.2
Cued-Free	5.6	5.8	5.4	2.2
Cued-Cued	7.8	8.1	7.3	5.5

SUBJECT VARIABLES

We have already mentioned the importance of some subjective variables on mnesic performances. The work reported in the paragraph above provides us with a more accurate understanding of these variables. The three groups of elderly subjects studied by Craik et al. (35) are of the same age. They differ, though, as regards verbal intelligence (Vocabulary scale, WAIS-R): the Old1 is equivalent to the young group, while the Old2 group is equivalent to the Old3 group. Presumably, the three groups of elderly subjects differ also in their percentage of daily activity, i.e. the percentage of time that the person is awake and occupied in active, as opposed to passive, pursuits. The Old3 group is the least active. Despite having the same age, the latter group is much lower than the other two elderly groups. Its performance improves when cues are provided both at encoding and retrieval, reaching the performance level of Old1 and the young people in free-cued and cued-free conditions. Correlation analysis does not indicate significant effects between age and word-recall conditions, whereas such effects are present between age and the vocabulary level of the subjects. Even when the vocabulary level is partialled out, age is not a predictor of cognitive ability.

Fig. 4 - Results obtained in a word recall task in 4 different conditions (35).



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If the data reported in Table XIV are plotted (Fig. 4), it is evident that differences among groups vary according to the task considered. For example, at free-free condition young subjects are superior to the Old1 group, while at cued-cued condition they are similar. Finally, at free-cued condition all groups seem different. Craik et al. (35) draw two major conclusions from this: 1) to get a full picture of cognitive changes with age, it is necessary to look at several different levels of ability; 2) models of cognitive aging that do not consider the complex interaction between tasks, environmental events and mental representations are potentially unsatisfactory.

Table XV - Mean scores obtained in a word recall task.

n=64	IQ/low	IQ/high
Elderly	3.67	4.34
Young	4.73	5.52

In young and elderly subjects, we have recently studied the influence of intelligence on an immediate memory task, using a list of 9 words. The elderly's ability was lower, but their performance was dependent on their IQ: subjects with a higher IQ gave better performances in both age groups. As is clear from Table XV, there is a gradual increase in performance from the elderly with a low IQ to the young with a high IQ.

SHORT AND LONG-TERM MEMORY

The model of human memory functioning described above must be integrated with the more classic view of memory, based on the time dimension; short- and long-term memory or recent- and remote-memory are the most commonly used terms. Man's biological make-up imposes obvious constraints in the processing of information. These constraints call for various types of changes to take place in order for information to be permanently stored. In particular, short-term memory, or primary-memory, is limited in terms of the amount of information it can contain and the time course over which material can be held. Information must be actively rehearsed to be retained in primary memory. If information is to be retained for a long period of time, it must be transferred to long-term memory, or secondary memory. Secondary memory is viewed as a store that can contain an unlimited amount of information for an indefinite time. Primary memory receives information from sensory memory; sensory memory represents the earliest stage of information processing and is characterised by rapid decay of information (200-300 msec). Complex interactions exist between the three types of memory and make them interdependent (36). Difficulty in any stage of memory creates an information bottleneck and performance suffers.

If we consider elements recalled, primary memory shows few if any losses with age. However, when more complex tasks or latencies are considered (e.g. backward memory span), older people tend to perform less well (32). The same result may be found in sensory memory: differences between young and elderly people seem to be irrelevant with certain simple tasks, but they become more marked when the amount of information to be analysed increases. Let us consider, for instance, Walsh's work (37), which is shown in Fig. 5. The relation between the number of items on a display and the interstimulus interval (ISI) required to escape masking is linear, but it varies according to the group considered: old subjects (70 year-olds) require more time to identify each letter on the display.

Fig. 5 - Backward masking obtained in three different age-groups (37).

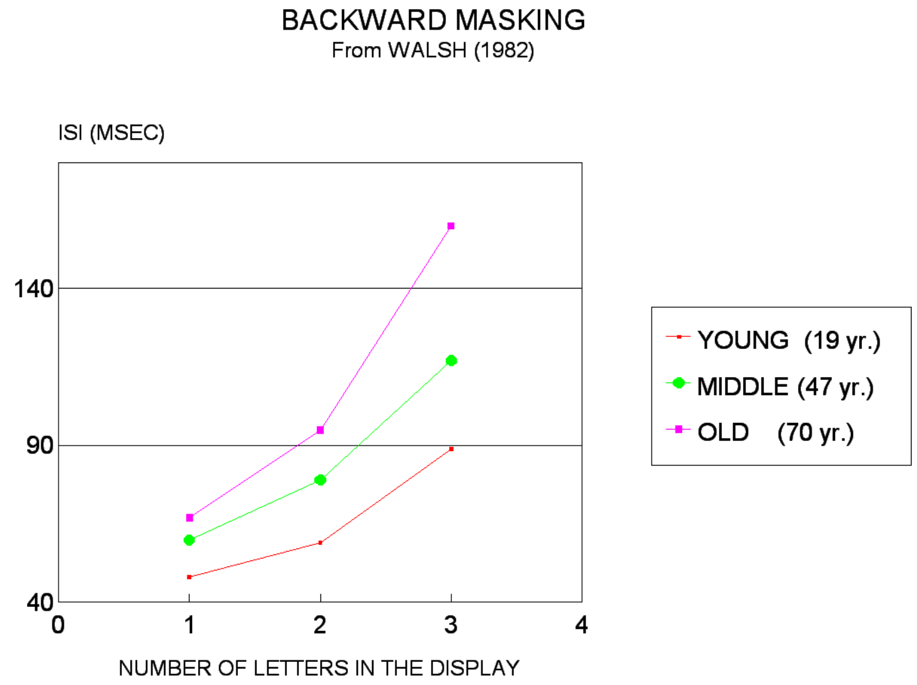

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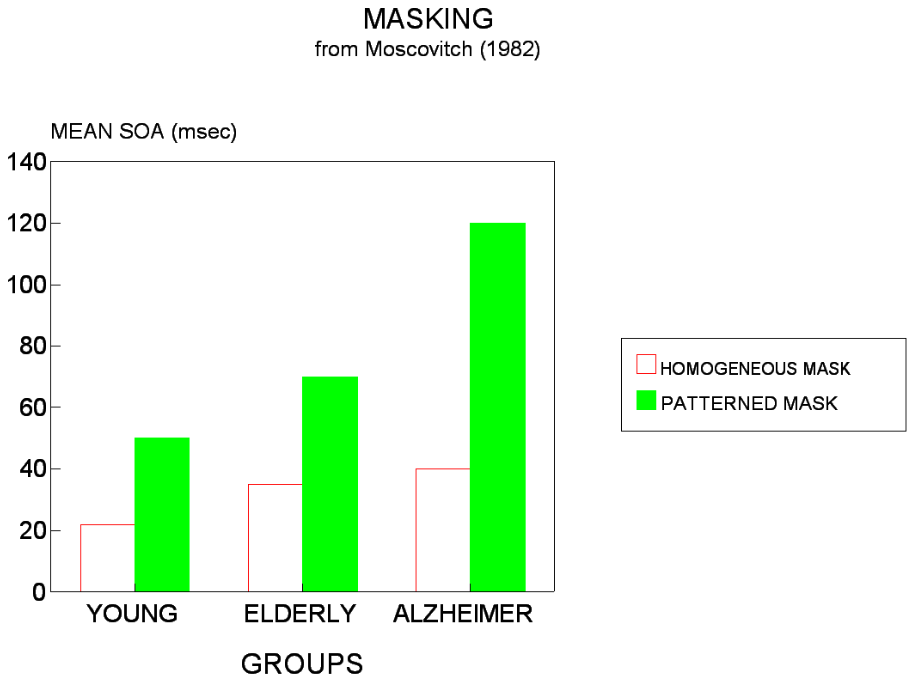
Fig. 6 - Results obtained with two distinct masking stimuli (39).



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Further evidence of sensory memory decline can be found in two works that have used backward masking.

In the first (38) a single letter was exposed for 1 msec followed by a patterned masking stimulus. A test letter was then clearly exposed and the subject's task was to decide whether or not the initial letter was the same as the test letter. Mean values of interstimulus interval at which subjects produced approximately 75% correct responses increased as a function of age. Backward masking function showed the greatest vulnerability to the effects of aging. The second work (39) indicates that this effect is more marked with a patterned mask than with a homogeneous mask (see Fig. 6).

COMPONENTS AND PROCESSING

Since it is possible to modify the subjects' performance by changing some task characteristics (see criterial task of the Jenkins model), it is evident that the decrease in performances cannot be attributed to storage and that any model based on a passive storage of information is strongly limitative. Memory is a complex function which is implemented through the combined effort of several brain regions, from the sensory to the associate to the motor one. The information that we receive precedes and follows other information and, therefore, has specific temporal and spatial characteristics. The transformation of the information received into its internal representation takes place through a sequence of components, which progressively transform it until it can be memorised. The components and their sequence may vary for each individual to the point of determining the efficiency and effectiveness of the mental representation. Due to the limitations in the frequency of information processing (which are intrinsic to all biological systems), the sequence of components used in memorising a specific piece of information causes not only quantitative, but also qualitative differences in the memory.

A very small quantity of energy is needed by each component to be carried out; since resources are limited, not all processes can be completed. Indeed, under certain circumstances, accessing these resources may cause competition. Typical examples are mental arithmetic or trying to remember a phone number while listening to instructions about an appointment and so on. If the resources are insufficient to complete the operations involved in these activities normally, the information is lost or errors are made, thus reducing performance. We should avoid believing that competition for the use of resources is an exceptional event: practically all cognitive functions, language in particular, require temporary storage of some information, while other information is acquired or manipulated. More or less constant memories are obtained on the basis of the overall resources and on the level of competition between the different activities.

DEPTH OF PROCESSING

Some years ago, Craik and Lockhart (40) argued that memory was a function of depth of processing, with deeper processing requiring more resources, but resulting in a more distinctive memory trace. The depth of processing determines the richness of the encoding and, presumably, of the retrieval. According to this view, encoding occurs upon a continuum of differing "levels" of information processing, with the level of the processing determining the nature and durability of the memorised information. Variations in the encoding operations have large effects on performance. For example, people who possess a great deal of prior knowledge of a particular domain and can thus encode domain-relevant information in a highly detailed and elaborate manner, exhibit greater retention of that information than subjects who possess no prior knowledge. According to Craik (36) the richness of the encoding is not, nevertheless, sufficient to guarantee the same richness of the information during retrieval: to this end it is, indeed, necessary to carry out the same operations present during encoding, and this can take place either through the innate capacity of the subject or when the subject's capacities are stimulated by external conditions.

Although the difficulty of defining operationally the depth of processing has limited the development of this model, research on memory and aging has been particularly influenced by this framework. Most hypotheses on the decline of mnesic functions and, more generally, of cognitive functions, refer to the theory of information processing: the elderly have a lower capacity for processing, hence their difficulties.

HYPOTHESES

The decrease could be due to: 1) a slowing of the individual components that make up processing; or 2) a reduction of the resources available.

As for the first point, we have already seen that, in the case of sensory memory, there are slowed components: as these components are propaedeutic to the subsequent ones, and because they are carried out thousands of times, it is understandable how even the smallest difference may markedly affect overall performance. More generally, the decline of mnesic functions is attributed to a widespread slowing of mental processes and, consequently, of memory. Evidence of this slowing is reviewed by Cerella (41), Salthouse (42) and Light (43) and, in the case of memory, it regards the rate of rehearsal during a memory task or the rate of scanning in memory search tasks. Indirect evidence of this slowing comes from an increase in the performance of elderly people as the rate of stimuli presentation decreases. By decreasing the presentation speed, more time is given to the subject for processing the stimuli, thus somehow imitating what naturally occurs in young people.

There is also enough evidence to claim that age differences increase with the cognitive complexity of the task: age differences will become larger based on the number of operations that must be carried out to meet the task. Cognitive slowing has been hypothesised as being due to: 1) a decline in the velocity of neural conduction and in the time of transmission across a synapse; 2) a reduced level of activation, perhaps mediated by the reticular activating system or some other subcortical structure; 3) a decrease in functional signal/noise ratio or an increase in the level of neural noise (42).

Every process requires a small quantity of energy to be executed.

Energy, or resources, are limited and they are responsible for the enhancing or enabling of certain cognitive processes (44). Craik and Rabinowitz (32) have suggested that older people may have fewer processing resources, so that some cognitive processes cannot be executed and others are carried out with reduced efficiency and efficacy. As a consequence, it would be reasonable to expect that highly practised operations would continue to be performed, while novel, complex and effortful operations would suffer. Unfortunately, these operations are responsible for the learning of new material and for the possibility of interconnecting information of different natures or which has been obtained in different moments. Reduced processing resources prevent information from being encoded at an adequate level, so that some contextual features are less effective at the time of retrieval (32).

I would like to stress here that both resource reduction and process slowing have quantitative and qualitative consequences on cognitive functions. As effectively illustrated by Salthouse (42), limited resources and slow processes can be assumed to influence all the subsequent phases of information processing. For instance, they can cause: 1) a possible shift in the sequence of components; 2) lower component efficiency; 3) differences in the type of representation as result of the reduced efficiency of each component.

WORKING MEMORY

Working memory should be briefly mentioned at this point. The working memory can be considered as a processing resource, in that it is presumed to have limited capacity, and it is thought to be relevant to a great variety of cognitive tasks. Tasks tapping working memory need simultaneous storage of recently presented stimuli and processing of additional information. Research confirms the presence of large age decreases in working memory tasks, but the deficit of the elderly lies primarily in the processing aspects of working memory rather than in storage. In this sense the problem is again attributable to processing and to the resource hypothesis formulated by Salthouse (44). Moreover, as more research is carried out, it becomes clearer that working memory is not a unitary construct. One possibility is that there is no single entity called working memory but rather a number of different working memories that are domain-specific and perhaps task-specific. Nevertheless, studies on working memory in the elderly are useful in reducing overall performance to its components.

CONCLUSIONS

Memory performance in the elderly is always poorer than in comparable young subjects. This applies both to traditional laboratory experiments, and to tasks with greater ecological validity (43). Performances vary remarkably based on subject and task characteristics; therefore, any hypothesis on the decline of mnesic functions must succeed in reconciling all the different aspects.

No single model, taken individually or collectively, provides an adequate account of the phenomena observed in normal and pathological aging. However, two models seem to synthesise memory results better than others. The first is Tulving's ternary memory scheme and the idea of a monohierarchical ordering of relative deficits: greatest in episodic and least in procedural. This seems to me a preferable way to synthesise the decline of memory performance with age. Whether the decline occurs along three or more systems is something which remains to be established. The second model one can refer to is that of processing resource. For reasons that are unexplained, processing slows down and resources decrease. Consequently, the subject is no longer able to follow efficiently the temporal course of sensory events, and to control the temporary storage of information: therefore, performance decays. The reduction of resources prevents the individual from resorting to them in order to neutralise deficits and, consequently, the subject is forced to modify the strategies applied in information processing. As the slowing increases and the resources decrease, there is a reduction in performance and an inability to complete some cognitive functions.

I believe that these two models, more than other ones, may create a link between psychological and neurological knowledge. From this perspective, additional research is desirable.

REFERENCES

1. Livingston G, Hawkins A, Graham N, Blizard B, Mann A. The Gospel Oak study. Prevalence rates of dementia, depression and activity limitation among elderly residents in inner London. Psychol Med 1990;20;137-146

2. Cutler SJ, Grams AE. Correlates of self-reported everyday memory problems. J Gerontol 1988;43;S82-90

3. Herzog AR, Rodgers WL. Age differences in memory performance and memory ratings as measured in a sample survey. Psychol Aging 1989;4;173-182

4. Tulving E. Memory: performance, knowledge, and experience. European Journal of Cognitive Psychology 1989;1;3-26

5. Tulving E. How many memory systems are there? Am Psychol 1985;40;385-398

6. Squire LR. Memory and brain. New York: Oxford University Press 1987

7. Craik FIM, Morris LW, Morris RG, Loewen ER. Relations between source amnesia and frontal lobe functioning in older adults. Psychol Aging 1990;5;148-151

8. Lim KO, Zipursky RB, Watts MC, Pfefferbaum A. Decreased gray matter in normal aging: an *in vivo* magnetic resonance study. J Gerontol 1992;47;B26-30

9. Mitchell DB. How many memory systems? Evidence from aging. J Exp Psychol [Learn Mem Cogn] 1989;15;31-49

10. Snodograss JG, Vanderwart M. A standardized set of 260 pictures: norms for name agreement, image agreement, familiarity, and visual complexity. J Exp Psychol [Hum Learn] 1980;6;174-215

11. Hultsch DF, Masson MEJ, Small BJ. Adult age differences in direct and indirect tests of memory. J Gerontol 1991;46;P22-30

12. Luszcz MA. Predictors of memory in young-old and old-old adults. International Journal of Behavioral Development 1992;13;147-166

13. Arbuckle TY, Gold D, Andres D. Cognitive functioning of older people in relation to social and personality variables. Psychol Aging 1986;1;55-62

14. Crook TH, Larrabee GJ. Interrelationships among everyday memory tests: stability of factor structure with age. Neuropsychology 1988;2;1-12

15. Crook TH, West RL. Name recall performance across the adult life-span. Br J Psychol 1990;81;335-349

16. West RL, Crook TH, Barron KL. Everyday memory performance across the life span: effects of age and noncognitive individual differences. Psychol Aging 1992;7;72-82

17. Read DE. Neuropsychological assessment of memory in the elderly. Can J Psychol 1987;41;158-174

18. Orsini A, Chiacchio L, Cinque M, Cocchiaro C, Schiappa O, Grossi D. Effects of age, education and sex on two tests of immediate memory: a study of normal subjects from 20 to 99 years of age. Percept Mot Skills 1986;63;727-732

19. Spinnler H, Tognoni, G eds. Standardizzazione e taratura italiana di test neuropsicologici. Ital J Neurol Sci 1987;6 (Suppl 8)

20. Lezak MD. Neuropsychological assessment. 2nd edn. New York: Oxford University Press 1983

21. Rey A. L'examen clinique en psychologie. Paris: Presses Universitaires de France 1964

22. De Renzi E, Faglioni P, Ruggerini C. Prove di memoria verbale di impiego clinico per la diagnosi di amnesia. Archivio di Psicologia Neurologia e Psichiatria 1977;38;303-318

23. Corkin S, Growdon JH, Sullivan EV, Nissen MJ, Huff FJ. Assessing treatment effects: a neuropsychological battery. In: Poon LW ed Clinical memory assessment. Washington: American Psychological Association 1986

24. Orsini A, Trojano L, Chiacchio L, Grossi D. Span di memoria immediata nella demenza. In: Salmaso D, Caffarra P eds Normalità e

patologia delle funzioni cognitive nell'invecchiamento. Milano: Franco Angeli 1990

25. Sgaramella TM, Bisiacchi PS. Difficoltà di memorizzazione negli anziani: limitazione del magazzino a breve termine o inadeguatezza delle strategie utilizzate ? In: Salmaso D, Caffarra P eds Normalità e patologia delle funzioni cognitive nell'invecchiamento. Milano: Franco Angeli 1990

26. Spinnler H, Della Sala S, Bandera R, Baddeley A. Dementia, ageing, and the structure of human memory. Cognitive Neuropsychology 1988;5;193-211

27. Salmaso D, Viola G. Il declino della memoria nel normale invecchiamento. Archivio di Psicologia Neurologia e Psichiatria 1989;50;527-541

28. Miller GA. The magic number seven, plus or minus two: some limits on our capacity for processing information. Psychol Rev 1956;63;81-97

29. Jenkins JJ. Four points to remember: a tetrahedral model of memory experiments. In: Cermak LS, Craik FIM eds Levels of processing in human memory. Hillsdale, NJ: Erlbaum 1979:429-446.

30. Kynette D, Kemper S, Norman S, Cheung H. Adults' world recall and word repetition. Exp Aging Res 1990;16;117-121

31. Gronwall DMA. Paced auditory serial addition task: a measure of recovery from concussion. Percept Mot Skills 1977;44;367-373

32. Craik FIM, Rabinowitz JC. Age differences in the acquisition and use of verbal information. A tutorial review. In: Bouma H, Bouwhuis DG eds Attention and performance X. Hillsdale, NJ: Erlbaum 1984:471-499

33. Waugh NC, Barr RA. Memory and mental tempo. In: Poon LW, Fozard JL, Cermak LS, Arenberg D, Thompson LW eds New directions in memory and aging: proceedings of the George A. Talland memorial conference. Hillsdale, NJ: Erlbaum 1981:251-260

34. West RL, Crook TH. Age differences in everyday memory: laboratory analogues of telephone number recall. Psychol Aging 1990;5;520-529

35. Craik FIM, Byrd M, Swanson JM. Patterns of memory loss in three elderly samples. Psychol Aging 1987;2;79-86

36. Craik FIM. Age differences in remembering. In: Squire LR, Butters N eds Neuropsychology of memory. New York: The Guilford Press 1984:3-12

37. Walsh DA. The development of visual information processes in adulthood and old age. In: Craik FIM, Trehub S eds Aging and cognitive processes. New York: Plenum Press 1982

38. Di Lollo V, Arnett JL, Krusk RV. Age-related changes in rate of visual information processing. J Exp Psychol [Hum Percept] 1982;8;225-237

39. Moscovitch M. A neuropsychological approach to perception and memory in normal and pathological aging. In: Craik FIM, Trehub S eds Aging and cognitive processes. New York: Plenum Press 1982

40. Craik FIM. Lockhart RS. Levels of processing: a framework for memory research. Journal of Verbal Learning and Verbal Behavior 1972;11;671-684

41. Cerella, J. Information processing rates in the elderly. Psychol Bull 1985;98;67-83

42. Salthouse TA. A theory of cognitive aging. New York: Elsevier Science Publishers BV 1985

43. Light LL. Memory and aging: four hypotheses in search of data. Annu Rev Psychol 1991;42;333-376

44. Salthouse TA. Working memory as a processing resource in cognitive aging. Developmental Review 1990;10;101-124