Episodic memory decay along the adult lifespan: A review of behavioral and neurophysiological evidence

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A B S T R A C T
The ability to learn and remember new information declines along life. Empirical evidence reveals that this deficit occurs unevenly with different types of memory. Episodic memory, which is referred to as the ability to remember our own experiences in a determined temporal and spatial context, is especially vulnerable to aging. Episodic information can be retrieved with or without the context information that took place when the episodic event was encoded. There is agreement that, with advancing age, the source information related to an episodic event is more susceptible to be forgotten than the event; however, there is no consensus regarding the age at which this decline begins, the speed of source-memory decline along life or the possible changes, due to aging, in neurophysiological activity during encoding of source information that is subsequently correctly retrieved. In an attempt to answer the first two issues, a behavioral study with 552 subjects from 20 to 80 years of age was conducted, which provided evidence of the exact age at which source memory starts to decline and of the speed of this memory loss along life. To address the last question, event-related potentials were recorded while young and old adults encoded source information, to investigate whether older adults generate memory traces different from young adults during encoding.

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1. Introduction

One of the most significant problems that people have to deal with as they get older is the loss of their memory abilities. Although the amount of memory deficit varies among individuals, it can be considered a universal phenomenon, since all humans will sooner or later experience some degree of memory difficulties. However, this deficit does not occur in all kinds of memories, some of them resist the passage of time better than others. Evidence has revealed that the elderly perform adequately in memory tasks that require less effort, as in implicit memory tasks, in which previously experienced stimuli affect subsequent behavior with or without the subject being aware of the previous presentation of these stimuli (Light et al., 1992), or in primary memory tasks in which subjects are required to repeat a set of stimuli in the same order (Puckett and Stockburger, 1988) and in recognition tasks in which subjects have to indicate if a stimulus has been previously presented or not (Craik and McDowd, 1987). Performance diminishes in tasks that demand a strong effort, as in working memory tasks in which subjects have to transform the information retained in their mind for a few seconds (Dobbs and Rule, 1989), in free recall tasks in which no clues are given to the subject to retrieve information (Schonfield and Robertson, 1966), and in prospective memory tasks in which subjects have to carry out some action without reminders (Einstein et al., 1995). Thus, when elderly people are required to retrieve or manipulate information employing their own resources without external help, performance tends to decline.

Episodic memory, which is referred to as the ability to remember our own experiences in a determined temporal and spatial context (Tulving, 1972), is especially vulnerable as a function of normal aging when it is evaluated by means of free recall tasks but not when it is evaluated by recognition tasks (Craik and McDowd, 1987). In view of the fact that episodic memory comprises information about the event itself and about the context related to that event, it has been possible to establish that, with advancing age, the source information related to an episodic event is more susceptible to being forgotten than the event (McIntyre and Craik, 1987).

Older adults perform poorer than young adults in episodic tasks in which subjects are required to retrieve the context or the source related to a specific event as has been shown by numerous studies (Spencer and Raz, 1995). However, there is no consensus regarding the following: At what age does source memory start to decline? How fast does this deficit occur along life? Is this deficit related to differences in the electrophysiological activity of young and old adults at the time of encoding source information that is subsequently correctly retrieved or forgotten? The following pages contain a review of the studies that have investigated these issues and describe some of the experimental evidence obtained at our laboratory. Firstly, a description is made of...
the most frequently employed tasks used to study source memory, and details of the source-memory paradigm employed in our experiments are provided. Then, an answer to the first two questions mentioned above is attempted by examining previous behavioral studies and our own experiments. The final part seeks to answer the third question posed. Only neurophysiological studies employing the event-related potential (ERP) technique are discussed, because a satisfactory report of research with other techniques is beyond the scope of this document.

2. Methods for studying source memory

The distinction between the event and the context in episodic memory has motivated the development of tasks that allow a separate evaluation of each. One of the first tasks employed to study item and source information was the so-called ‘remember/know’ procedure (Tulving, 1985). In this task, during the test session, subjects are instructed to provide a ‘remember’ answer if they are able to retrieve any contextual information related to the item that was presented for the first time in the study session, or to endorse a ‘know’ response if the item seems familiar to them but they are unable to retrieve contextual information from the study session. This task relies on the subject’s introspection, since it is not possible to verify the actual information retrieved by the subject at each trial, or to identify the nature of this contextual information. Despite this shortcoming, this procedure has been extensively employed to test episodic memory. A more objective method to determine whether recognition memory was or was not accompanied by retrieval of contextual information consists of presenting each item in a specific context during a study session, followed by a test session in which subjects are required to retrieve the context of each item presented in the previous session. This task will be referred to hereafter as a source-memory paradigm. This procedure permits measurement of the subject’s ability either to retrieve or not to retrieve the specific source under evaluation.

In the studies described here a source-memory paradigm previously used in a functional magnetic resonance imaging (fMRI) study was employed (Cansino et al., 2002). Fig. 1 illustrates the stimuli used to produce a high level of item memory by employing perceptually rich and distinctive pictorial color images of common objects as stimuli. A total set of 108 images was used for the behavioral experiments (72 items for the encoding session and the total set for the retrieval session), while for the ERP experiments a total set of 180 images was employed (120 items for the encoding session and the total set for the retrieval session). The images for the encoding session of each subject were randomly selected from the total set of images.

During the encoding session, the screen was continuously divided into quadrants by a cross. The center of the cross was located in the middle of the screen and served as the eyesight fixation-point in the behavioral experiments. In the ERP recordings, an additional small cross appeared inside the quadrant just previous to the stimulus, with the purpose of preventing eye movements once the trial had begun. The stimuli were displayed for 1000 and 500 ms in the behavioral and ERP experiments, respectively. The interval between the onset of successive stimuli was 3000 and 4500 ms for the behavioral and ERP experiments, respectively. The ERP experiments consisted of longer trials to allow subjects to blink between trials. Subjects were allowed to respond from the beginning of the stimulus presentation until the end of the trial. This time setting was used for both, encoding and retrieval sessions.

During encoding, the stimuli were presented randomly within one of the quadrants of the screen; each quadrant had the same probability of being selected. The task was to indicate whether the image represented a natural or an artificial object. In the retrieval session, a five push-button response panel was employed with four buttons arranged in two rows of two keys each. The left keys of each row were accessed by the index finger while the right keys were pressed by the middle finger. These four keys represented each of the screen quadrants. The fifth key was located in the lower part of the panel to be pressed by the thumb. During retrieval, the images were presented in the center of the screen and subjects were instructed to judge whether the image was new or old (previously presented in the encoding session). If the image was new, subjects pressed the lower key of the response panel and if it was old, subjects indicated at which position on the screen the stimulus was presented during the encoding session, by pressing one of the four keys. Subjects were instructed to guess and to randomly select one of the four keys if they were unable to remember the position of the stimulus at encoding.

This source-memory paradigm has proved to be especially useful to study brain activity related to the successful and unsuccessful encoding and retrieval of source memory (Cansino et al., 2002). The reason for this is that typical source-memory experiments have employed two-choice tasks, such that subjects are instructed to select between two different contexts, namely, the context in which each item was presented during the study (e.g., visual vs. auditory, female voice vs. male voice, first list vs. second list). With this procedure, the probability to provide a correct source judgment by chance is of $P_{\text{chance}} = 0.5$, thus, performance is expected to be high in order to consider a correct source response truly correct and not based on a ‘lucky guess’. The consequence of this high performance is that few incorrect source judgments are usually available to be compared with correct performance. In contrast, the four-choice task employed in the present experiments reduced the probability of providing a correct source judgment by chance ($P_{\text{chance}} = 0.25$) and thus increased the proportion of source judgments, both correct and

![Fig. 1. Two examples of the stimuli employed in the source-memory task, representing an artificial and a natural object.](image-url)
incorrect. This approach produces more powerful contrasts between these conditions.

3. Source-memory decline across lifespan

Numerous studies have compared groups of young adults, usually under 30 years of age, with old adults, typically above 60 years of age, while performing source-memory tasks. These studies have tested diverse contexts: the modality, visual or auditory, in which stimuli were previously presented (McIntyre and Craik, 1987), who presented the information (Schacter et al., 1991), whether the stimuli were previously perceived or imagined (Henkel et al., 1998), the voice that presented the information (Glisky et al., 2001), if the participant asked for, answered or listened to certain information (Brown et al., 1995), or in which room, color or set of stimuli were the items previously presented (Spencer and Raz, 1994). All of these experiments confirmed that older adults perform poorer in the source-memory task than younger adults. However, it has not been possible to establish when in the adult lifespan this kind of memory starts to decline. Several longitudinal studies have explored episodic memory changes during different life periods for 3 years (Hultsch et al., 1992), 4 years (Luszcz, 1998), 5 years (Christensen et al., 1997), 6 years (Comijs et al., 2004), 8 years (Andrews et al., 2002) and even 16 years (Zelinski and Kennison, 2001). The findings from all of these studies cannot fully answer the questions addressed here because none of them cover the complete adult lifespan.

In contrast, Uttl and Graf (1993) evaluated a sample of 302 men and women ranging from 15 to 74 years of age; the mean number of subjects per decade was 50. Subjects were invited to visit an exhibit on the human memory: Half of them were told that their memory would be tested (intentional condition) and the rest were invited to answer the memory test only after leaving the exhibit (incidental condition). Spatial source memory was tested using a map test in which subjects had to locate the objects they had seen in the exhibit. Source-memory performance declined with age and this decline started in the last decade (65 to 74 years of age). Performance between the incidental and intentional conditions did not differ with this naturalistic procedure. Similar results were observed when everyday memory tasks were simulated (Crook et al., 1993) and in an experiment conducted in a laboratory setting (Téllez-Alanís and Cansino, 2004). These results challenged those from other studies in which spatial memory was reported to decline gradually with age (Moore et al., 1984; Salthouse et al., 1988). Of the other cross-sectional studies that have evaluated memory decay along the adult lifespan (Baltes and Lindenberger, 1997; Salthouse, 2001; Park et al., 2002; Salthouse, 2003) none has focused on source memory. Instead, a broad range of different memory types or cognitive processes have been measured in different age groups. The analysis of a data subset from the Betula Prospective Cohort Study reported by Erngrund et al. (1996) provided more information about source-memory decline than when these data were reported previously in combination with other memory tasks (Nilsson et al., 1997). The source-memory task in the Erngrund study consisted of answering whether made-up facts were learned before or within the experiment, and if subjects thought that they were learned during the experiments, they had to indicate the voice or the color with which the information was learned. In this study, source-memory decline was observed after 55 years of age.

Cross-sectional investigations employing a wide range of memory tasks are interesting because large samples of subjects have been tested: n = 206 (Salthouse, 2001), n = 345 (Park et al., 2002), n = 687 (Baltes and Lindenberger, 1997), n = 1,250 and n = 2,450 from the Wechsler Memory Scale III and the Wechsler Adult Intelligence Scale III, respectively (Salthouse, 2003). However, cross-sectional studies are based on the assumption that young adults will be similar to older adults when they reach their age, and that older adults were like the young adults at their age (Salthouse, 2000). Results from these studies indicate that memory and other cognitive functions decline linearly with age. However, a meta-analysis of 91 studies revealed that episodic memory decline is moderately related with age before 50 years of age, but increases after this age (Verhaeghen and Salthouse, 1997).

Five-hundred and fifty-two healthy subjects, 92 from each decade between 20 and 80 years of age (50% females in each decade) were tested with the source-memory paradigm described above as part of an investigation undertaken by our laboratory, in which a larger sample will be subsequently examined, seeking to evaluate several variables. This paradigm allows the analysis of recognition or item memory and of source memory. Item recognition consists of the ability of identifying the image as old, independently of whether the subject retrieves its context correctly or not; and source memory implies correct recognition along with the retrieval of the correct spatial position where the image was presented at encoding.

Fig. 2 illustrates scatter plots between recognition and source-memory performance as a function of age. The proportion of variance for recognition ($R^2=0.15, P<0.0001$) predicted by age was markedly lower than that for source memory ($R^2=0.42, P<0.0001$) predicted by age. For recognition, the slope of the fitted line was $-0.32\% (SE=0.03)$ per year; for source memory, the slope was $-0.76\% (SE=0.04)$ per year. Analysis of variance examining the differences among decades for item recognition ($F_{3,546}=22.4, P<0.0001$) and for source memory ($F_{3,546}=76.0, P<0.0001$) yielded significant effects. Post hoc Tukey test for item recognition data showed that subjects between 21 and 30 years of age outperformed those of 41 or older; subjects between 31 and 60 years performed above subjects of 61 or older, and subjects between 41 and 70 years old performed better than 71 year-olds or older. For the source-memory data, post hoc analyses revealed significant differences along the decades except between 41 and 60 years of age.

These results confirm that item recognition is scarcely affected by age, while source memory is more vulnerable. Although item recognition declines slightly with age, present data show that it started as early as 41 years of age. Nilsson et al. (1997) observed the earliest difference for name recognition between 45 and 50 year-old adults. Moreover, source memory showed a dramatic decline with age, with a fragile plateau between 40 and 60 years of age since performance also seems to decline in these two decades as can be deduced from Fig. 2. These results contrast with other cross-sectional studies measuring source memory, which have located the starting age of its decline at 55 years (Erngrund et al., 1996) or as late as 65 years (Uttl and Graf, 1993), while present data showed a starting age of decline as early as 31 years of age.

These dissimilarities could be attributed to the different number of items tested and to the length of item presentation time during encoding sessions: 20 facts at a rate of 5 s per item (Erngrund et al., 1996), 22 objects from the exhibit examined during unlimited time (Uttl and Graf, 1993) and 72 images, each presented during 1 s in the present data. Task complexity is evidently not equivalent in the three studies. The gradual decline in source-memory performance observed in the present study was quite similar to that detected in other memory and high-demanding cognitive tasks: free recall, matrix reasoning (Salthouse, 2001), working memory, long term memory (Park et al., 2002) and intellectual abilities as measured by psychometric tasks (Baltes and Lindenberger, 1997; Salthouse, 2003). Together, these results indicate that, with aging, individuals experience a broad-spectrum cognitive impairment.

The present source-memory paradigm allowed to measure reaction times (RTs) as well, which have been rarely reported, since source memory was measured by means of paper-and-pencil procedures. The proportion of variance of RT means during item recognition ($R^2=0.19, P<0.0001$) and correct source-memory responses ($R^2=0.23, P<0.0001$) predicted by age was notably similar, as suggested by Fig. 2. The slope of the fitted line was $6.8\ms (SE=0.6)$ per year for RTs during item recognition, and $7.4\ms (SE=0.6)$ per year for RTs during source-memory judgments. RTs for item recognition responses ($F_{3,546}=25.8, P<0.0001$) and for source-memory responses ($F_{3,546}=32.4, P<0.0001$) were significantly different along the decades. Tukey tests revealed that for both, item recognition and source-memory responses, RTs were not
significantly different in subjects belonging to two continuous decades. Thus, subjects in their 20s produced shorter RT than subjects in their 40s and older; subjects in their 30s produced shorter RT than subjects in their 50s and older; subjects in their 40s produced shorter RT than those in their 60s and older; and in their 50s, subjects produced shorter RT than those in their 70s.

These outcomes suggest that memory-processing time increases gradually with age, independently of the different cognitive effort demanded for each type of response. A generalized slowing down in cognitive processing with age has been extensively accepted (Salt-house, 1996). However, the rate of slowing in the specific case of source memory, which was ~7 ms per year, has not been previously reported.

In sum, source memory, tested under the experimental conditions demanded by the paradigm employed, starts to decline gradually at 31 years of age and this occurs at a rate of −0.76%. This percentage is roughly equivalent, according with the amount of images tested in our paradigm, to forgetting the source of one item every 2 years.

4. Neural activity underlying source-memory decline

The empirical behavioral evidence described above demonstrates that source memory declines gradually with age; however, the reasons for this decline are still unclear. Episodic memory decline has been attributed to deficient encoding processes, as for example, not being able to create associations between new events and existing neural traces of information related to that event (Chalfonte and Johnson, 1996), and also to inefficient retrieval strategies (Craik and McDowd, 1987). Neurophysiological signals are especially suitable to investigate whether this poor source-memory performance is related or not to changes in brain activity underlying encoding or retrieval of source memory.

A few studies have recorded ERPs in young and older adults while subjects are engaged in source-memory tasks. Some of them have used the ‘remember/know’ procedure together with a source-memory paradigm (Trott et al., 1997; Mark and Rugg, 1998; Friedman and Trott, 2000; Duarte et al., 2006) and others, a source-memory paradigm (Wegesin et al., 2002; Li et al., 2004). Most of these investigations analyze data from the retrieval section to compare neural activity for ‘remember’ items with that for ‘know’ items or with neural activity for correct new items (Mark and Rugg, 1998; Duarte et al., 2006), or brain activity for correct source responses with activity for correct new items.

![Fig. 2. Mean percent responses and mean reaction time of recognition (left) and correct source (right) as a function of subject age in a sample of 552 subjects: 92 per decade between 21 and 80 years of age. Item recognition corresponds to items correctly identified as old with or without its context; while source memory corresponds to correctly recognized old items with correctly retrieved spatial location. Linear regressions are shown in solid lines and quadratic fits in dashed lines.](image)

![Fig. 3. Grand average ERP waveforms recorded by selected electrodes during encoding for subsequent correct and incorrect source judgments in young (left) and old adults (right).](image)
encoding source-memory study with older adults (Friedman and Trott, 2000) and during retrieval (Trott et al., 1997). In this study, two lists of sentences were presented during encoding; each sentence contained two nouns displayed sequentially in each trial. Subjects were instructed to study the words and the list where they appeared. During retrieval, pairs of words were sequentially presented at each trial and the subjects’ tasks consisted of providing three successive responses: first, to judge whether each word was new or old; second, if the word was considered old, subjects endorsed a ‘remember- know’ judgment; and third, subjects indicated in which list they had seen the word. ERP’s recorded during encoding were analyzed to search for subsequent memory effects, which consisted of segregating the studied items according to whether their encoding were analyzed to search for subsequent memory effects, which consisted of segregating the studied items according to whether their context (list) was correctly retrieved or not (Friedman and Trott, 2000). No subsequent memory effect was observed between correct and incorrect source responses, but the effect was evident in both groups for items subsequently judged as ‘remember’, compared with those subsequently judged as ‘know’. Thus, the effect was not detected in their source memory paradigm, which provides an objective method to measure source memory, but in their ‘remember-know’ procedure, which relies on subjects’ introspection; although both response-types were provided by the same subjects. The authors concluded that these apparently contradictory results could be explained by the fact that their subjects probably encoded other contextual information that was employed to endorse their ‘remember’ responses, but this information was not the specific temporal context [list].

An experiment was conducted by our group to investigate if the neurophysiological activity recorded by the ERP technique changed in old adults compared with young adults employing the described source-memory paradigm. The interest was to examine the neural correlates of successful and unsuccessful source memory during encoding to establish whether the impairment of this kind of memory in the elderly is related to neural activity changes during encoding. Young (21–25 years old) and old adults (71–80 years old) participated in the study. Each age group comprised fourteen healthy subjects (8 females) with equivalent schooling years. The percentage of correct source responses was 49% (SD=13) and 36% (SD=7) for young and old adults, respectively. Source judgments of studied items significantly exceeded the chance level of 25% [F(1,26)=74.74, P<0.001] in both groups as revealed by post hoc Tukey tests. Thus, subjects performed above chance probability in a four-choice task (P=0.25).

To search for subsequent memory effects, brain activity recorded during encoding was compared for subsequently recognized images attracting correct source responses with those attracting incorrect source responses. Preliminary results from this still unpublished study showed significant subsequent memory effects in both groups. Fig. 3 depicts the mean waveforms recorded in both groups in two frontal and two parietal sites. This effect was predominant at frontal sites in both groups but still significant at posterior sites. The only difference observed between groups was the onset of this effect. In the young, the effect was significant 200 ms after onset of the stimulus in frontal sites, after 400 ms in central sites and after 600 ms in posterior sites; while for the older adults, this effect started 600 ms after onset of the stimulus in anterior, central and posterior sites. Differences between groups were observed only in F4, F8 and T8 between 1000 and 1100 ms. The differences consisted in a more prominent subsequent memory effect in young than in old adults: larger amplitude differences between images subsequently attracted a correct and an incorrect source judgment. These results agree with those reported in the only previous encoding source-memory study with older adults (Friedman and Trott, 2000). However, their subsequent memory effects were observed between ‘remember’ and ‘know’ judgments and not between correct and incorrect source responses as in the present study. Another remarkable difference is that, in the previously mentioned study, subsequent memory effects started equally at 400 ms post-stimulus onset in young and old adults, while in our study the onset of this effect differed by 400 ms between the young (200 ms) and the old (600 ms) adults.

No conclusive answer can be formulated to the last question posed in this study due to the small number of studies that have been performed with old adults, and to the diversity of methods and of the kind of brain activity analyzed in each of them. Results from our laboratory indicate that the neural activity underlying successful and unsuccessful source memory only differed in temporal and strength activation between young and old adults. Whether these changes are generated by the cognitive effort demanded by the task or by the general slowing down of processing and cognitive impairment related with aging, remains an open question.

5. Conclusions

Episodic memory declined gradually across the adult lifespan when examined by means of high-demanding source-memory tasks. Evaluation of this decay along the life decades showed that it started at 31 years of age or after the end of the first adult decade (21 to 30 years old). The rate of this decline, measured in a sample of more than 550 subjects, is roughly equivalent to the increase in probability of forgetting that one item has been previously seen every 4 years, and to the increase in probability of being unable to retrieve the source of one item every 2 years. The speed of recognition of one item and of source retrieval of one item diminished by about 7 ms/year. The neural activity underlying source-memory processes during encoding showed an average onset delay of approximately 400 ms and the amplitude was attenuated in older adults compared with young adults. The similar gradual decline observed in source memory as a function of age with that detected in other memory, cognitive, and intellectual functions is remarkable. When these findings are coupled with the preliminary evidence suggesting that neural activity manifested a delay and weakness in old adults this may indicate that source-memory decline is only one of the expressions of a widespread cognitive decline expected with aging characterized by a strong effect on performance as the task gets harder. This generalized decline may be due to the important chemical and structural changes that take place in the central nervous system as organisms become older. The next relevant step in this research field will be to explore the factors that account for the variability observed in cognition abilities among individuals across the adult lifespan.

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Baltes, P.B., Lindenberger, U., 1997. Emergence of a powerful connection between neurocognitive and intellectual functions is remarkable. When these findings are coupled with the preliminary evidence suggesting that neural activity manifested a delay and weakness in old adults this may indicate that source-memory decline is only one of the expressions of a widespread cognitive decline expected with aging characterized by a strong effect on performance as the task gets harder. This generalized decline may be due to the important chemical and structural changes that take place in the central nervous system as organisms become older. The next relevant step in this research field will be to explore the factors that account for the variability observed in cognition abilities among individuals across the adult lifespan.

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