Modeling the reminiscence bump in autobiographical memory with the Memory Chain Model

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In this article, we researched the distribution of the autobiographical memory by using the Galton-Crovitz cueing method. We obtained random memory samples of 1587 subjects between 10 and 70 years through the Internet. We checked for telescoping, but we found no overall effect for temporal displacement. We did find more evidence for a 'reminiscence bump' between 10 and 30 years, which can be explained by differentiating the memory distribution into two separate functions, namely a decline function and an encoding-sampling function. Our new Memory Chain Model, which can incorporate both functions, was used to fit the empirical distributions and gave good fits.

Autobiographical memory

Wagenaar (1986) examined his own autobiographical memory by using an elaborate technique. Every day he recorded one or two events of his daily life during a period of 6 years. He wrote down four aspects of every event. He recorded *what* the event was, *who* was involved, and *where* and *when* it happened. The events were also scaled for saliency, emotional involvement, and pleasantness. He found, among other things, that pleasant events were better recalled than unpleasant events. The recall of the events took about one year. In 1879, Sir Francis Galton (1879) had already developed a less elaborate technique to measure autobiographical memory whereby he inspected a word until an association came to mind. If the association referred to an event from his past, he dated the memory. He found that 39% of his memories were from his boyhood and youth, 46% were dated to be from subsequent manhood and the rest, 15% of his memories, referred to "quite recent events". A century later, Herbert Crovitz continued Galton's research (Crovitz & Schiffman, 1974; Crovitz & Quina-Holland, 1976). Crovitz and Schiffman asked 98 subjects to inspect a list of 20 words one by one and to describe the memory associated with each word that first came to mind. At the end of the inspection the subjects were asked to date each memory as accurately as they could. When Crovitz and Schiffman plotted the frequencies of memories against age, they found that the frequency of memories decreased with age. They suggested that the shape of the curve conforms to a specific function, namely a power function.

The Galton-Crovitz cueing method aims to obtain a random sample of all memories, stratified through the use of suitable keywords. The frequency of the memories recalled from a given time period, such as the year 1995, can be interpreted as an estimate for the probability that one will recall a memory from this year. It would be a mistake to interpret the curves of Galton-Crovitz experiments as frequencies. Instead, the Galton-Crovitz cueing method measures a probability density function of memory age. When deriving such functions it is also important to take into account that there is a hard limit on the maximum age of a memory, namely the age of the subject at the time of recall. How important it is to take into account the age of the subject, was shown by Rubin, Wetzler, and Nebes (1986). They combined the memory age distributions of different experiments with each different cue words and found evidence for a reminiscence bump between the subjects' age of 10 and 30 years, provided that the subjects are at least 40 years old. We will try to replicate the results of Rubin et al. by testing subjects between 10 and 70 years old within one experiment.

We assume that the observed memory distribution (Figure 1, diamonds) is formed by two functions. The decline function (Figure 1, triangles) describes the proportion of forgotten memories as a function of the time past between experiencing the event and the present. When an event happened ten years ago, then there might be for example a 59 percent chance that the memory about the event has been forgotten. Thus, the chance that the memory is retrieved is 41%. When an event happened twenty years ago, there might be a 71 percent chance that the memory has been forgotten.

The second function is the encoding-sampling function (Figure 1, squares), which describes the intensity of the memories as a function of the age of the subject at the occurrence of the event. Some

theories assume that this function is constant, while others predict that when subjects are fifteen years old, they store memories better than when they are thirty years old.
The upper panels of Figure 1 give the observed memory distribution, the decline function and the encoding-sampling function for subjects aged thirty and fifty years using a constant encoding-sampling function. The lower panels use a non-constant encoding-sampling function and clearly depict how a decline and a non-constant encoding-sampling function can cause a reminiscence bump.
Therefore, when a 30-year old subject tries to remember an event that happened ten years ago (i.e., he was twenty), there might be 47 percent chance that the memory is successfully retrieved, while when a 50-year old subject tries to remember an event that happened ten years ago (i.e., when he was forty), there might be a chance of 38 percent of retrieval.

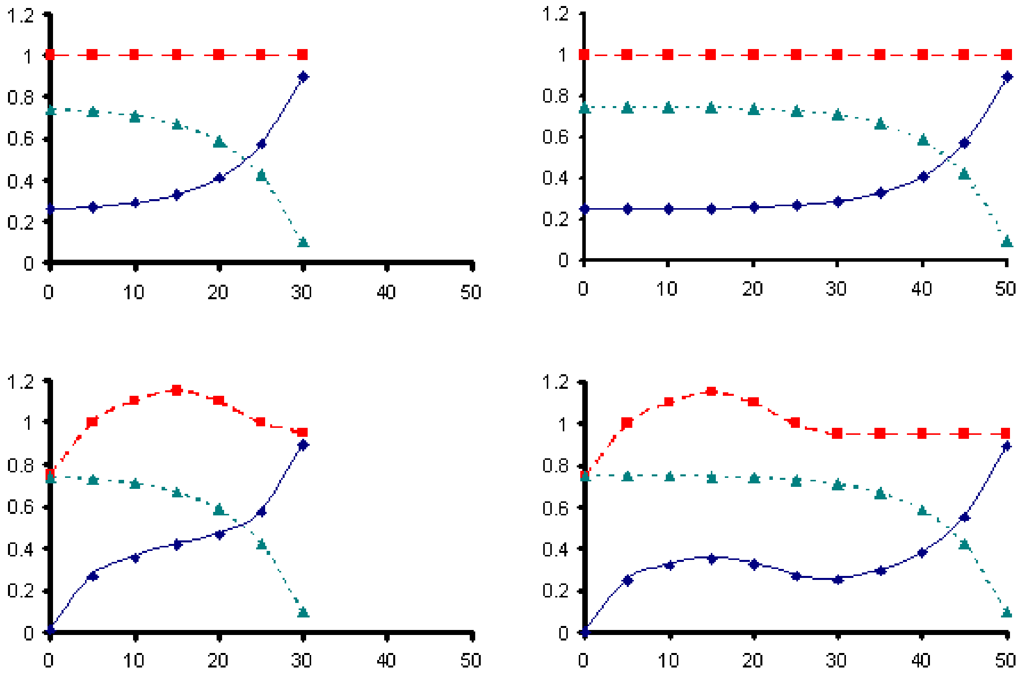

Figure 1. Upper panels: Observed memory distribution (? diamonds), the decline function (? triangles) and the encoding-sampling function (¦ squares) for subjects aged thirty years (left panel) and fifty years (right panel) using a constant encoding-sampling function. Lower panels: Observed memory distribution (?), the decline function (?) and the encoding-sampling function (¦) for subjects aged thirty years (left panel) and fifty years (right panel) using a non-constant encoding-sampling function.

Telescoping Effect

While researching autobiographical memory using the Galton-Crovitz cueing method one relies on the reports of the subjects. The most common systematic displacement of events in time is the telescoping effect (Friedman, 1993). Telescoping is an error made in the dating of the occurrence of events, which may be dated either too recent (forward telescoping) or too remote (backward telescoping). The telescoping effect was not considered in the experiments of Crovitz and Schiffman (1974) and Rubin et al. (1986). We will ask subjects when certain public news events happened to check whether there is a systematic displacement in time. Prior research (Wright, Haskell & O'Muircheartaigh, 1997; Janssen, Chessa & Murre, subm.) showed that the telescoping effect is smaller when a 'calendar' answering format ('On June 17, 1997', 'In the beginning of August 2000' or 'In 1998') is used, than when an 'ago' format ('3 hours ago', '5 weeks ago' or '2.5 years ago') is used, because there is no rounding effect.

Because the format that the subjects use to date the personal events is the same as they use for public events, namely the 'calendar' format, the resulting effect can be expected to be similar for both events. Furthermore, there is evidence that people use personal events for dating public events and vice versa. In Loftus and Marburger (1983), subjects reported more victimizations when they were asked whether they were victims of crime in the last six months than when they were asked whether they were victims of crime since a certain landmark event (the eruption of Mt. St. Helens, which happened exactly six months earlier). This experiment showed that there is a temporal relationship between the storage of personal and public events. Another example of this interaction is a flashbulb memory (Brown & Kulik, 1982). Flashbulb memories are memories for the circumstances in which one first learned of a very surprising and consequential (or emotionally arousing) event (Brown, Shevell & Rips, 1986). For instance, many people know exactly what they were doing when they first heard of the attacks on the WTC buildings. They have a personal memory (where they were, what they were doing) linked with the public event (the news of the attacks).

Internet

The Galton-Crovitz test was presented on the Internet (http://memory.uva.nl/testpanel/gc/). The Internet is a research environment, which has advantages over other research settings. The most important advantage is the high number of subjects. The Internet setting of an experiment has possible threats to its reliability, because the researcher does not know under which circumstances the test is taken. The researcher also has to test the internal validity, because the on-line experiment can measure different psychological variables than its laboratory equivalent.
It is difficult to give a meaningful value for the reliability and the validity of random memory samples, but we could calculate test-retest and split-half reliabilities for another Internet-based test. This Daily News Memory Test (DNMT) had satisfactory reliabilities (Janssen, Meeter & Murre, subm.). We measured the internal validity by comparing the scores of laboratory subjects with the scores of Internet subjects. We found that the Internet subjects performed better than the laboratory subjects, probably was this due to a difference in motivation. Krantz, Ballard, and Scher (1997), Buchanan and Smith (1999) and Epstein, Klinkenberg, Wiley, and McKinley (2001) also compared the two settings and found that the results had the same psychometric proportions.
Most subjects in this experiment (90.1%) also participated in the DNMT, because subjects, who completed that test, were sent an email, asking them to participate in the Galton-Crovitz test.

Memory Chain Model

We will try to fit the results of the experiment with the Memory Chain Model. The model describes the development of the memory strength of an item in time during both the learning and the forgetting phase (Murre & Chessa, subm.). In the model, memory strength is determined by three postulates:

1. The number of 'memory representations' of a learned item determines memory strength.

2. The life span of a memory is determined by the decline of memory representations in one or more neurobiologically motivated 'memory stores' and by the induction (transfer) of representations between each pair of successive stores, which are arranged in a feed forward fashion (see Figure 2).

3. Successful retrieval of a memory depends on the number of representations in all the stores and on the quality of a retrieval cue.

According to the model, memory representations can be seen as points in some space that denotes one or more memory stores. When an item is learned, a number of representations will be encoded to form an initial memory in the first incoming store (see Figure 2). After a person has learned the item, a process of decline starts. The number of representations in a store will usually decrease, on average, as a function of time, while points may simultaneously be copied to a subsequent store (transfer or induction). Every store has its own decline rate. In the model the stores are arranged in order of decreasing decline rate, which reflects a cascade of neurobiological processes that consolidate short-term memories into longer-term representations (McGaugh, 2000). Memory representations can only be transferred to the next store in the chain.

The eventual retrieval of a memory is depicted by the model as the selection of subspaces within each store, which will be searched for memory representations. The quality of a cue determines the size of the subspace that will be searched. Retrieval is successful when a representation has been found in an arbitrary store. The more representations are stored, the easier a memory can be retrieved.

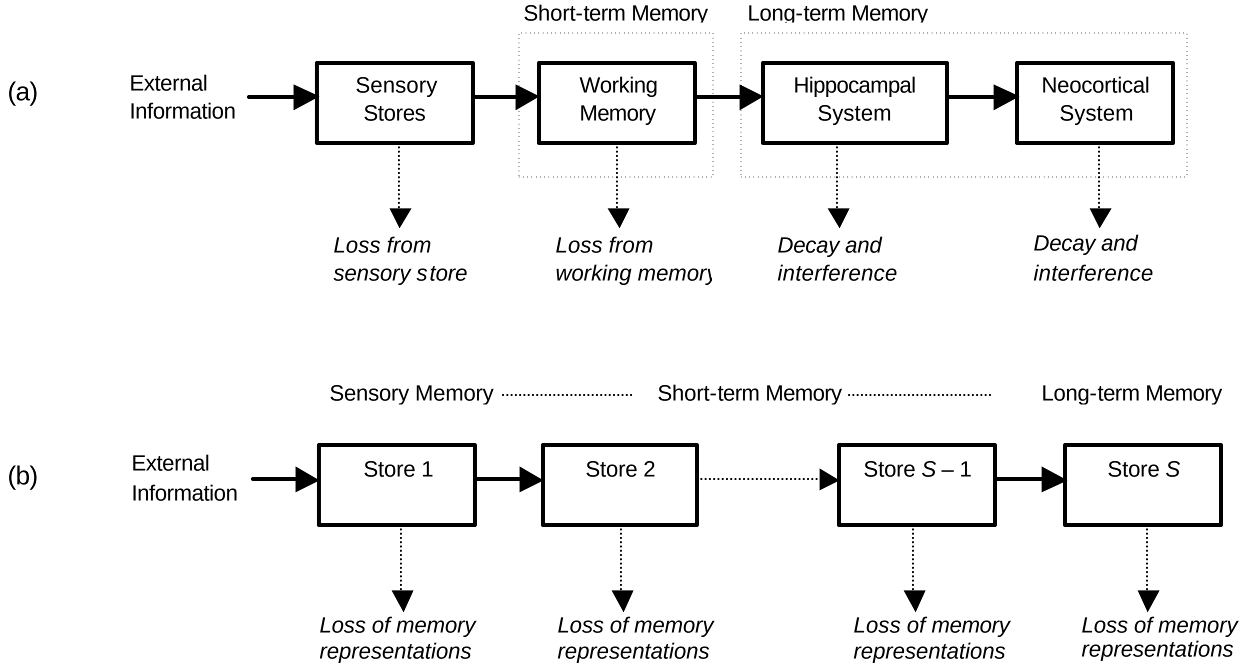

Figure 2. (a) Storage systems for a memory at different time scales, with feed forward induction between stores and decline within stores. (b) Abstract representation used in the Memory Chain Model.

The Memory Chain Model is completely specified by one function, the so-called *intensity function*, which gives the expected number of memory representations after a retention interval. An encoded memory reaches a number μ_1 of memory representations at the end of a stimulus presentation and subsequently declines according to a function $\bar{r}(t)$, for retention intervals t. With the quality of a retrieval cue denoted by q, the intensity function r for one memory store has the form

$$r(t) = \underbrace{\mu_1}_{\text{encoding}} \; \underbrace{\bar{r}(t)}_{\text{storage}} \; \underbrace{q}_{\text{retrieval}}, \qquad (1)$$

The *decline function* $\bar{r}(t)$ specifies the storage of a memory in time. The decline functions for two and three stores are given in Murre and Chessa (subm.). Encoding can be interpreted as being either constant or non-constant. Encoding can be manipulated in an experiment by varying learning times. Cue quality q, which takes values between zero and one, is assumed to be time-independent. This parameter can be manipulated by varying the number of cues (Wagenaar, 1986).

The Memory Chain Model has proven to be neurobiologically plausible in a recent study, where the model was applied and fitted to animal and human data regarding amnesia and other memory disorders. A lesion to a certain part of the brain amounts to partly of fully removing the contribution of one or more stores in the Memory Chain Model, which gives rise to typical pathological functions such as the Ribot gradient (Murre, Chessa & Meeter, subm.). In each of the data sets considered, Store 1 could be conceived of as the hippocampus and Store 2 as the neocortex. The Memory Chain Model has also proven to fit learning and forgetting data in normal subjects very well, for which we considered more than 100 data sets from the literature and from our own experiments (Murre & Chessa, subm.). The experimental data could be fitted without additional assumptions and without modifying the underlying mathematical model.

Method

Subjects

The subjects consisted of 827 men and 760 women, whose average age was 39.89 years. The group was divided into six age groups. The first group consisted of subjects between the ages of 10 and 20 (N = 124), the second between 20 and 30 (N = 362), and so on (N = 380, N = 344, and N = 278), and the last group was made up of subjects between the ages of 60 and 70 years (N = 99). The subjects made the test on the Internet and they did not get any financial reward for their participation.

Materials

We selected a total of 64 cue words from Paivio, Yuille, and Madigan (1968). The nouns had a score of at least 6.00 on Concreteness, Imagery and Meaningfulness scales and were rated A or AA in Thorndike-Lorge frequency. To assess the telescoping effect, the subjects were also given ten questions about when certain international and national public events took place. These public events had to be events that everyone could remember. Therefore, the public news questions were selected from the Amsterdam Media Questionnaire (AMV) developed by Klomps (2001) and the Daily News Memory Test (DNMT), developed by Meeter, Murre, and Janssen (subm.).

The AMV is a retrograde amnesia test. It was used to make public news questions about events from the fifties until the nineties. The original AMV contains open questions about public events that have been answered correctly by at least 70% of a reference population of normal subjects. The selected AMV questions were changed into public news questions. For example "Which princess died in Paris at the end of August 1997?" was changed into "When did princess Diana die in Paris?" Events that could be dated through deduction, such as Olympic games or presidential elections, were not selected.

The DNMT is an online retrograde amnesia test (http://memory.uva.nl), to which new questions are added every day. It was used to derive public news questions about events from the years 2000, 2001 and 2002. Multiple-choice questions from the DNMT that were answered correctly by 90% of the reference population were selected. The DNMT questions were changed as well. For instance "In which sea did the Russian submarine Kursk sink on August 13, 2000?" was changed into "When did the Russian submarine Kursk sink?" The test contained 68 news questions from the period 1953-2002. Every subject received 10 news questions, selected randomly from the period after their tenth birthday.

Procedure

After they read the instructions, the subjects were randomly given ten cue words. The subjects had to describe the first memory about a personal event that came to mind, while inspecting each word. The participants were explicitly told that the reported events did not have to be interesting. This is because we wanted to prevent that the subjects would only describe major events from their lives, instead of those personal events that first came to mind. They were not told that they had to assign dates to these events later in the test, because we did not want them to only describe events they could easily date like birthdays or holidays.

After each description, the subjects were given a public news question. We asked them when the event happened. The participants answered the question in a 'calendar' format ('On June 17, 1997', 'In the beginning of August 2000' or 'In 1998'). By alternating the recalling of personal events and the dating of public news events the subjects were less likely to use a single period as starting point for all their memory searches. When a subject finished describing the memories and answering the public news questions, he was given the cue words and the accompanying memories again. The subjects were asked when these personal events took place.

Results

Checks

The subjects could take the Galton-Crovitz test more than once, but in this article we did not analyse the data of subjects who took the test more than two times. Answers referring to dates in the future or to dates before the subject's date of birth were omitted.
We found that there was no overall telescoping effect. In Figure 3 the median error in days per question is plotted against the average actual age of the public news event. Most news events did not show a significant forward or backward telescoping effect.

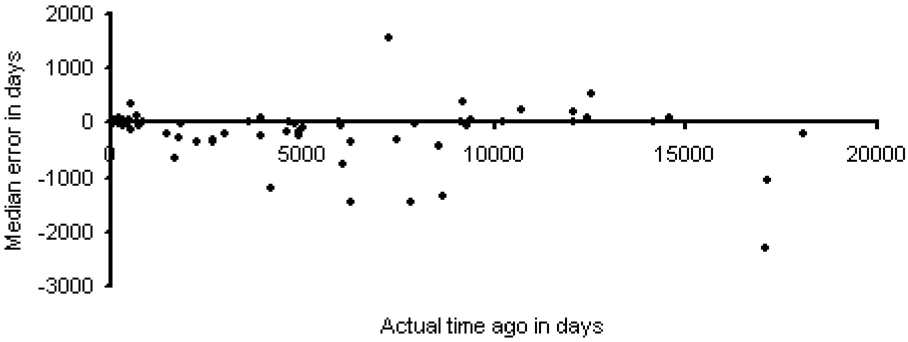

Figure 3. The telescoping effect: The signed errors in dating the public news questions plotted as a function of the average real ages of the events. Positive errors denote backward telescoping and negative errors denote forward telescoping.

Memory Age Distributions

Figure 5 shows the empirical probabilities of the memory ages for each age group. The probabilities of recalled memories of the last year are plotted separately because these probabilities are so high (between 68.8 and 40.8 percent, see Figure 4) that the rest of the figures would become unreadable. Three observations can be drawn from the data: (1) Subjects of all age groups recall most memories from their recent past (e.g. the last year), (2) a reminiscence bump emerges for subjects older than 40 years, for memories formed, roughly, between ages 10 and 30, and (3) the reminiscence bump remains on the same position for different age groups. The first observation can be explained from the characteristics of memory storage, as subjects generally tend to forget more as the time between memory encoding and recall increases. The reminiscence bump is caused by different factors. The Memory Chain Model in its present state can give us an explanation for this phenomenon in terms of the encoding-sampling function. In order to illustrate our ideas we introduce the following notation. Let *z* denote the age of a subject at the time of testing. We denote by *w* the age of a memory at the time of testing, which means that *z* – *w* is the subject's age at which the memory was encoded. Equation 2 thus gives the following expression for the intensity of a memory at testing age *z*, which was encoded at age *z* – *w*, when we take *q* = 1 without loss of generalization:

$$r(w) = \mu_1(z - w)\,\bar{r}(w). \tag{2}$$

The retention lag is, of course, equal to the memory age *w*. The intensity function contains the information for deriving an analytical expression for the probability density function of memory age. The intensity function is a probability density function, up to a constant of normalization, for the lifetimes of memory representations. Memory age is equivalent to the minimum lifetime of a memory at the time of retrieval. The lifetimes that are greater than this minimum value contribute to the probability of sampling a memory with that age, which yields the following expression for the probability density or mass function (pdf) *f*(*w*):

$$f(w) = \mu_1(z - w)\int_w^{\infty} \bar{r}(t)\,dt. \tag{3}$$

Technical details about the exact form of the probability distribution of memory age for one and more stores are given elsewhere (Murre & Chessa, subm.). Equation (3) enables us to infer the shape of the initial encoding μ_1 as a function of subject age *z* – *w* at the time of memory encoding. This function reveals the actual location of a possible reminiscence bump, which is indicated by the subject's age at which the expected number of encoded memories reaches its highest value. If the encoding function μ_1 has a maximum at age *z* – *w*, then the probability density function *f* does not necessarily have a maximum at memory age *w*, since the behavior of *f* is also determined by memory storage, which in our model is represented by the decline function $\bar{r}$. The actual subject age, at which a possible reminiscence bump occurs, should therefore be adjusted according to the effects of storage. As recall declines for older memories, the actual reminiscence bump may often be shifted to younger subject ages with respect to the bump observed in the pdf *f*.

The product form of Equation (3) enables us to separate and estimate the effects of encoding and storage from the memory age frequencies observed, which are represented by *f*. We first transformed the frequencies to normalized values that are independent of the encoding and then fitted expressions proportional to the integral over the decline function on the right-hand side of Equation (3) to these values. This resulted in an estimate of the decline function, which we subsequently used to derive the shape of the encoding function from the data. The empirical pdf *f* and the estimated encoding-sampling function $?_1$ are both shown in Figure 5 for each of the six age groups. The data clearly show the presence of a reminiscence bump. Although the bump is not visible in the results of the younger subjects, it is clearly visible in the estimated encoding-sampling functions. The location of this maximum encoding-sampling seems to remain fixed over the different age groups. There is considerable variance in the encoding-sampling estimators, so that we derived an average encoding-sampling function over the six age groups. The result, which is shown in Figure 6, gives a much better idea of the shape of the encoding-sampling function, which peaks between ages 13 and 18. The encoding-sampling rapidly increases until this age range, after which it decreases at a lower rate until about age 40 and then stabilizes around some constant value.

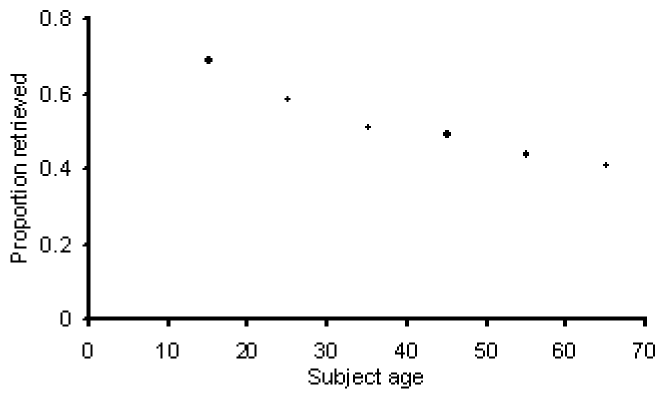

Figure 4. Proportions of retrieved memories for the six age groups, only for events from the past year.

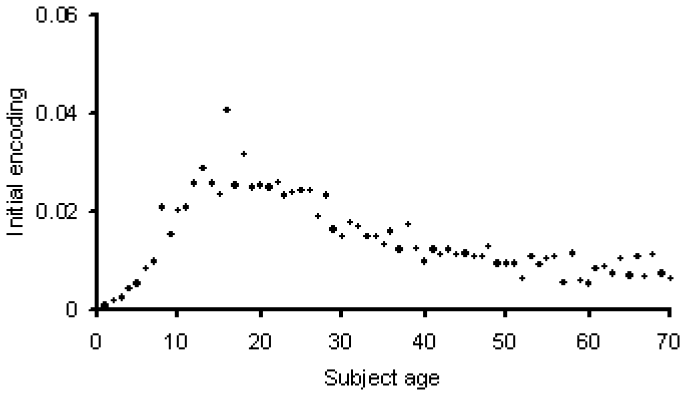

Figure 6. Encoding-sampling as a function of subject age, averaged over the six age groups. Values are normalized as in Figure 5.

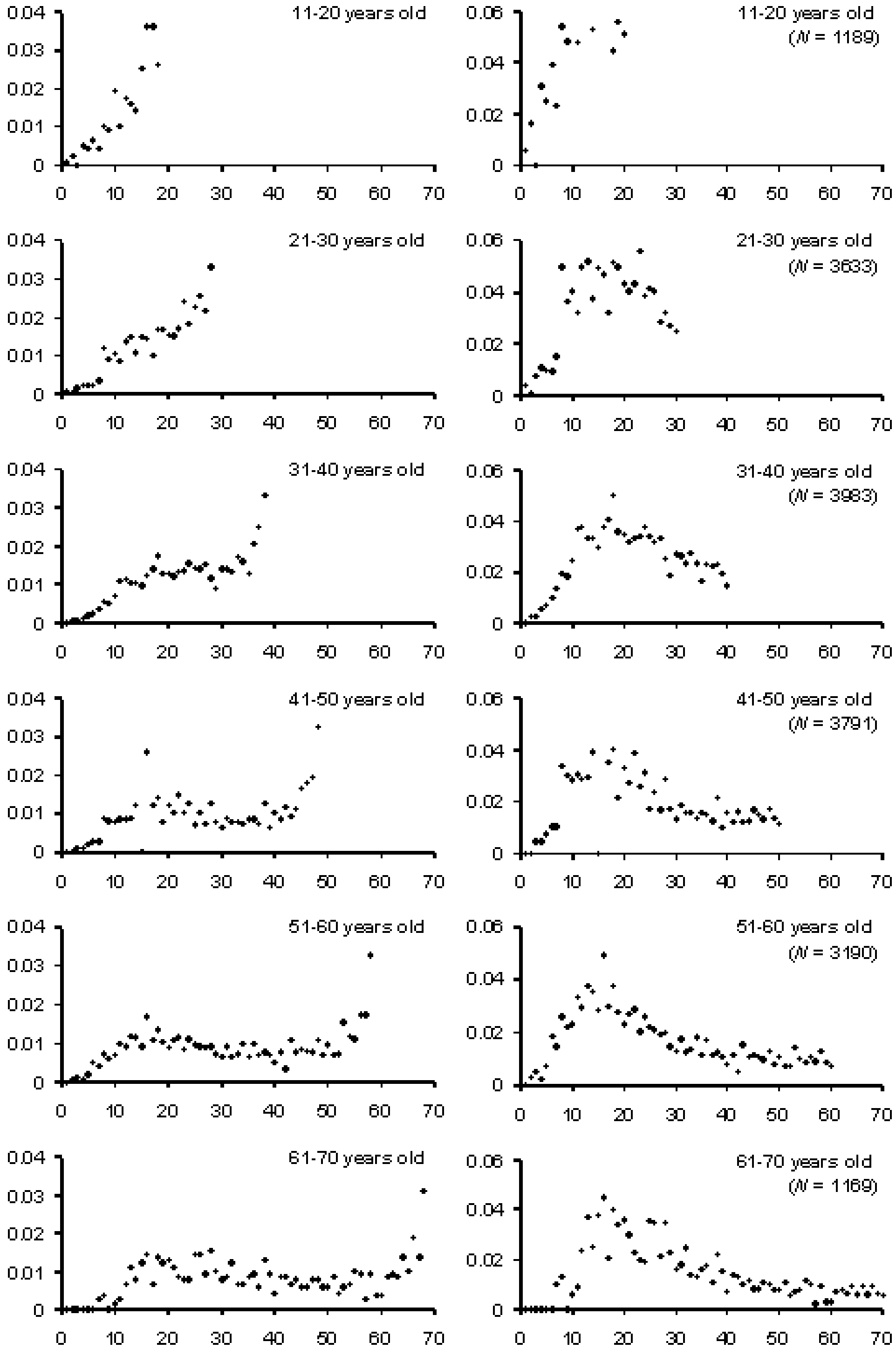

Figure 5. Left panel: Proportions of retrieved memories as a function of subject age at the time of encoding-sampling. The two highest values, which fall in the two most recent years, are excluded in order to better visualize the shape of the distribution. Right panel: Estimated encoding-sampling for every subject age. Encoding-sampling values are normalized such that the total encoding over the age range sums to 1.

Discussion

Our experiment confirms the existence of a reminiscence bump in the retrieved memories of subjects as reported by Rubin et al. (1986). We tested a large number of subjects, all using the same instructions and cue words. The results of our data analysis yield a more accurate estimate for the age at which the bump peaks, namely at the time when subjects were between 13 and 18 years old. This age range is an estimate for the age interval during which the expected number of encoded memory representations reaches its highest value.

We also successfully divided the memory age distribution into two functions, a decline function, which depends of the time past and an encoding-sampling function that depends on the age of the subject. Furthermore, we checked the results for telescoping, but there was no overall temporal displacement.

The neurobiologically motivated Memory Chain Model was introduced as a model for memory encoding, storage, and retrieval, and offers a possibility to derive separate estimates for memory encoding and storage from the proportions of memory ages reported by subjects. To our knowledge, this is a new approach for data analysis and modeling in the field of autobiographic memory. Since the Memory Chain Model also represents a unified framework of different retention measures, it would be possible to derive recall probability functions, the signal-detection measure *d'*, and other measures, like Ebbinghaus' savings function, from the estimated encoding and storage parameters. We consider these topics to fall beyond the scope of this study, so we did not include examples of these functions in this article.

In the present study, we considered only one possible hypothesis for the cause of the reminiscence bump, namely memory encoding that varies as a function of the age of a subject at the time of encoding. We did not investigate a detailed list of other hypotheses, such as consolidation or re-sampling, which may lead to an increase of retention at greater retention lags. We briefly investigated this hypothesis within the context of the Memory Chain Model, assuming a constant encoding over the age range of a subject. Based on the model, this hypothesis does not give rise to pdf's with more than one mode, so the model does not predict a reminiscence bump. These probability distributions of memory age based on the model did not fit the data well, so this hypothesis would probably be rejected. In the near future, we will compare the results of male with female subjects and the results of Dutch with American subjects, to test whether there are any biological or cultural differences between these groups and to test the alternative hypotheses.

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