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CORTEX 180 (2024) 35–41

Available online at www.sciencedirect.com

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Viewpoint

Did H.M. exhibit accelerated long-term forgetting? Measuring forgetting in amnesia

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ARTICLE INFO

Article history:
Received 21 August 2024
Reviewed 2 September 2024
Revised 4 September 2024
Accepted 11 September 2024
Action editor Michale Kopelman
Published online 17 September 2024

Keywords:
Accelerated long-term forgetting
Amnesia
Forgetting rates
Recognition

ABSTRACT

The early investigations of patient H.M. inaugurated the modern era of memory research. During the 1970s and 1980s, a key debate over whether H.M. with bilateral medial temporal lobe lesions exhibited accelerated long-term forgetting attracted an increasing interest in forgetting research among amnestic patients. Huppert and Piercy (1979) examined H.M.'s performance in visual recognition at 10-minute, 1-day, and 7-day intervals and suggested that H.M. was subjected to rapid forgetting compared with Korsakoff patients and healthy participants reported in Huppert and Piercy (1978). In contrast, Freed et al. (1987) employed the same experimental paradigm and concluded that forgetting rates in H.M. did not differ from those in healthy controls. These incompatible findings highlighted a methodological challenge in measuring forgetting in the cross-group comparison design, where closely equalising the initial performance between patient and control groups is usually suggested. The re-analysis in this viewpoint, using both linear- and nonlinear-based modelling, reconciled the discrepancy between the aforementioned studies. Our results indicated that the rate of forgetting in H.M. did not differ from that in healthy controls, regardless of whether the initial performance was closely matched. Here, we suggest that the cross-group comparisons in forgetting studies do not necessarily seek a perfect match in initial performance unless the risks of confounding encoding and retrieval processes can be effectively controlled.

1. Introduction

Following the initial observations in temporal lobe epilepsy (see reviews by Butler et al., 2010; Contador et al., 2021), amnesiacs with a variety of other brain damages or diseases have also been reported as presenting with a rapid loss of information labelled accelerated long-term forgetting (Lah et al., 2017; Lammers et al., 2022; Studer et al., 2024; Weston et al., 2018). However, this phenomenon has recently been called into question and revisited as possibly resulting from testing and scoring methods (Cassel & Kopelman, 2019; Della Sala

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https://doi.org/10.1016/j.cortex.2024.09.003

et al., 2024). The debated issue centres on whether forgetting is accelerated in amnesia, possibly due to the poorer initial level of performance. When measuring forgetting rates, amnestic patients exhibited lower starting points; hence should this baseline difference be corrected, and how should forgetting be measured (Della Sala et al., 2024; Wixted, 2022)? In this viewpoint, we revisited this key debate dating back to the 1970s and 1980s, based on studies investigating whether the characteristics of forgetting delineated different aetiologies of amnesia (Freed & Corkin, 1988; Freed et al., 1987; Huppert & Piercy, 1978, 1979). These studies motivated a growing body of subsequent neuropsychological research to compare forgetting rates in amnesic disorders originating from diverse conditions (Christensen et al., 1998; Kopelman, 1985; Kopelman & Stanhope, 1997; Squire, 1981).

In particular, Huppert and Piercy reported that H.M., the famous case of amnesia due to the bilateral medial temporal lobe resection (Corkin, 2002; Scoville & Milner, 1957), exhibited rapid forgetting in visual recognition memory compared to the Korsakoff patients with diencephalic lesions at 1-day and 7-day delays (Huppert & Piercy, 1979), whereas Korsakoff patients performed comparably at each delay to the healthy controls (Huppert & Piercy, 1978). The authors concluded that there was a functional basis for distinguishing amnesias associated with lesions in medial temporal or diencephalic structures. A decade later, Freed et al. (1987) argued that the conclusions drawn by Huppert and Piercy (1979) were problematic as the initial performance of H.M. was not equal to that of the control group. Using the same experimental paradigm and procedure with success in matching initial acquisition, Freed et al. (1987) demonstrated that the overall forgetting between H.M. and the healthy controls did not differ, as evidenced by the null group × delay interaction in the analysis of variance. This conclusion was upheld at an extended delay interval of six months (Freed & Corkin, 1988).

Freed et al.'s (1987) findings suggested that when the initial performance of a person with amnesia is closely matched to that of healthy participants through prolonged encoding time or increased number of repetitions, no differential forgetting was observed between patient and control groups. In turn, this implies that the poorer initial acquisition, as shown by H.M., was associated with a more rapid rate of forgetting. However, a range of behavioural studies in healthy participants has indicated that the initial degree of acquisition does not affect the slope of forgetting, suggesting forgetting rates are independent of the levels of initial performance (Bahrick, 1984; Meeter et al., 2005; Peng et al., 2024; Rivera-Lares et al., 2022, 2023; Slamecka & McElree, 1983). As such, the lower initial performance of H.M. in the study by Huppert and Piercy (1979) may not necessarily result in differential rates of forgetting in relation to healthy controls. If this were the case, there would be no need to perfectly equate the initial degree of acquisition between patient and control groups, which comes at the cost of introducing confounding variables, such as uncontrolled encoding strategies and measuring memories from different ages.

Additionally, the conclusions in Huppert and Piercy (1979) were drawn based on the comparisons between H.M. and Korsakoff patients from their study in 1978 rather than directly comparing to healthy controls. In fact, the decline in H.M.'s recognition performance between adjacent retention intervals, relative to healthy controls, was less than four percent. Moreover, their statistical inferences employed one two-tailed z-test for recognition at 10 min ($z = .32$, $p > .05$), demonstrating an approximate match in baseline performance, and two one-tailed z-tests for 1-day ($z = 1.61$, $p = .05$) and 7-day ($z = 2.55$, $p = .005$) delayed performance, evidencing differential forgetting rates between H.M. and Korsakoff group. The z-test assumes that the true standard deviation of the population is known. Yet, this assumption was not satisfied. To examine the question of whether H.M. exhibited accelerated long-term forgetting when his performance was not equated to that of the controls, we re-analysed the yes/no recognition data extracted from the original reports (Freed et al., 1987; Huppert & Piercy, 1978, 1979). This re-analysis employed both linear and non-linear modelling, enabling a direct comparison between H.M. and healthy participants while also allowing for further exploration of forgetting rates with different retention functions.

2. Methods

2.1. *Huppert and Piercy (1978, 1979)*

H.M. and six healthy adults were tested individually. In the learning phase, each participant was presented with 120 slides of coloured pictures photographed from magazines and was instructed to remember them. Attempting to equalise the initial level of performance, H.M. received 10-s exposure to each slide while healthy participants inspected each picture for 1 s. After learning, yes/no recognition tests were administered 10 min, 1 day, and 7 days later. In each test, a sample of 40 of the original pictures was presented, randomly intermixed with 40 new pictures as distractors. Participants were asked to indicate for each picture whether or not they had seen it previously. Recognition performance was measured using percent correct responses (i.e., the percentage of correctly classified "yes" and "no" responses divided by the total number of presented items) at each delay with a possible range of 0–100% and a chance performance at 50%.

2.2. *Freed et al. (1987)*

H.M. was tested for yes/no recognition four times over the course of a year with different sets of materials, while seven healthy participants were tested once. To equalise initial performance, H.M. was allowed to inspect 120 pictures twice, with each picture presented for 10 s, totalling 20 s of exposure per picture. Participants in the control group viewed each picture for 1 s. Recognition performance was assessed at varying retention intervals. Specifically, H.M.'s performance was evaluated on four different schedules: at 10 min, 1 day, and 7 days during the first testing; at 10 min, 1 day, and 3 days during the second; at 10 min, 3 days, and 7 days during the third; and at 10 min, 1 day, 3 days, and 7 days in the final testing. Among seven healthy volunteers, three were tested at 10 min, 1 day, and 7 days, while the remaining four were tested at 10 min, 1 day, and 3 days. Thus, different data points were collected at each retention interval. Other aspects of

experimental procedure remained the same as Huppert and Piercy (1978, 1979).

2.3. Data extraction and simulation

Data extraction: The data analysed for this paper were drawn from Huppert and Piercy (1978, 1979) and Freed et al. (1987). The means and standard deviations (*SDs*) of recognition performance for the six healthy participants who took part in the original study were extracted from Table 1 and Fig. 1 in Huppert and Piercy (1978). H.M.'s performance was extracted from Fig. 2 in Huppert and Piercy (1979, Experiment 2) using the Web Plot Digitizer software (Rohatgi, 2019). Individual data from Freed et al. (1987) were taken directly from their Tables 1 and 2.

Data simulation: Given that Huppert and Piercy (1978) only provided data in aggregate form via summary statistics, i.e., the trial-specific data were not available, six datapoints were simulated for healthy controls at each of the three delays to perform the analysis. These datapoints were obtained by repeatedly simulating from a normal distribution until the difference between the means and *SDs* of the simulated data and the original report were less than .01 in absolute value. This approach was preferred to (1) matching the simulated and original means by generating more than $n = 6$ samples per delay, which would affect statistical significance, and was also preferred to (2) generating one set of $n = 6$ samples per delay with no control of the distance between the summary statistics of the simulated datapoints and the paper. This would lead to samples having means and *SDs* very different from those reported in the original paper, which would also affect the results. The parameters of the normal distribution for the simulation were the means and *SDs* from Huppert and Piercy (1978).

2.4. Statistical analysis

Statistical analyses were performed in the R Statistical Environment (R Core Team, 2023). Percent correct responses at each recognition test were summarised as means and *SDs*. Recognition performance was analysed using linear mixed-effects models. Given that H.M. was tested only once in Huppert and Piercy (1979), the dependent variable was the difference in the percentage of correct recognition responses between healthy controls and H.M. The model included retention interval (10 min, 1 day, and 7 days) as the fixed effect and, as random effect, a random intercept by participant. As H.M. was tested four times in Freed et al. (1987), the outcome variable remained percent correct responses in recognition tests and the fixed effects were group (H.M. vs. healthy controls), retention intervals (10 min, 1 day, 3 days, and 7 days), and their interaction; with by-participant random intercepts. The mixed-effects models were constructed following the recommendations from Barr et al. (2013). The models started with a maximal fixed and random effect structure according to the study design. If a model failed to converge, random effects showing high correlations would be omitted from the model and the estimation rerun.

The rates of forgetting were compared between H.M. and healthy controls using the curve-fitting approach. The extracted recognition data at each time interval were fit into three widely discussed two-parameter retention functions: exponential-power, power, and logarithmic functions (Radvansky et al., 2024; Rubin & Wenzel, 1996). The goodness-of-fits of the models were assessed using the Akaike information criterion (*AIC*), Bayes information criterion (*BIC*), and Pearson's coefficient (R^2). For each group, the unconstrained models were specified allowing two parameters (intercept a and slope b) freely estimated. The slope parameter from H.M. was maintained to establish a constrained model for healthy controls. This constrained model was then compared with its unconstrained counterpart using the incremental *F*-test. A significant *F*-test ($p < .05$) would indicate that the slope of the retention function varied statistically, suggesting differential forgetting rates between H.M. and healthy controls.

3. Results

3.1. Recognition performance

The average performance in recognition tests is described in Table 1. The mixed-effects model for Huppert and Piercy (1979, Experiment 2) indicated that the difference in recognition performance between H.M. and healthy controls did not significantly change over time, F (2, 10) = 3.83, $p = .058$. Pairwise comparisons with Bonferroni adjusted *p*-value suggested no significant change in performance difference between healthy control and H.M. from 10 min to 1 day, t (10) = −1.70, $p = .359$, 1 day to 7 days, t (10) = −1.04, $p = .970$, or 10 min to 7 days, t (10) = −2.74, $p = .063$. As to Freed et al. (1987), given the close match in initial performance, only the main effect of retention interval approached significance, F (3, 21) = 11.37, $p < .001$. Neither the main effect of group, F (1, 3) = .24, $p = .652$, nor the group × interval interaction, F (3, 21) = 2.41, $p = .096$, was found to be significant. The results from both studies, therefore, are compatible rather than in contradiction, suggesting no differential change in recognition performance over a 7-day interval.

3.2. Forgetting

Retention curves for the averaged data in H.M. and healthy adults followed a negatively accelerating pattern: a rapid decline shortly after encoding and a gradual levelling with the passage of time (Figs. 1 and 2). Given the limited data points available, three retention functions have equivalent explanatory power for Huppert and Piercy's (1978, 1979) averaged data, all with an R^2 value higher than .90 (Table 2). In contrast, individual performance displayed a wide range of variability, more evidently in the data from Freed et al. (1987). As such, unsatisfactory fits with an average R^2 value of .42 were observed across three function candidates for Freed et al.'s data (1987) (Table 3). The analysis of forgetting for the yes/no recognition performance consistently rejected differential rates of forgetting between H.M. and healthy controls since no significant difference between unconstrained and constrained models for all fitted retention functions in both studies. Taken together, no convincing evidence supported that H.M. exhibited accelerated long-term forgetting in visual recognition memory, compared to healthy participants.

Table 1 – Descriptive statistics of extracted/simulated recognition data from original studies (percent correct responses, means ± SDs, sample sizes in parentheses).

	Retention intervals			
	10 min	1 day	3 days	7 days
Huppert and Piercy (1978, 1979)				
Controls ($n = 6$)	78.37 ± 4.65	69.75 ± 3.12		62.13 ± 4.39
Controls (simulated)	78.37 ± 4.65 (6)	69.75 ± 3.12 (6)		62.13 ± 4.39 (6)
H.M.	73.31 (1)	60.90 (1)		50.97 (1)
Freed et al. (1987)				
Controls ($n = 7$)	78.21 ± 7.32 (7)	72.50 ± 8.90 (7)	63.75 ± 5.95 (4)	60.00 ± 6.61 (3)
H.M.	78.75 ± 5.95 (4)	60.42 ± 3.15 (3)	60.00 ± 8.66 (3)	64.58 ± 13.01 (3)

Notes: The mean recognition data of six healthy controls were taken from Table 1 in Huppert and Piercy (1978). The *SDs* of recognition data from six healthy controls were extracted from Fig. 1 in Huppert and Piercy (1978). H.M.'s performance in Huppert and Piercy (1979) was extracted from their Fig. 2. Individual data from Freed et al. (1987) were drawn from their Tables 1 and 2

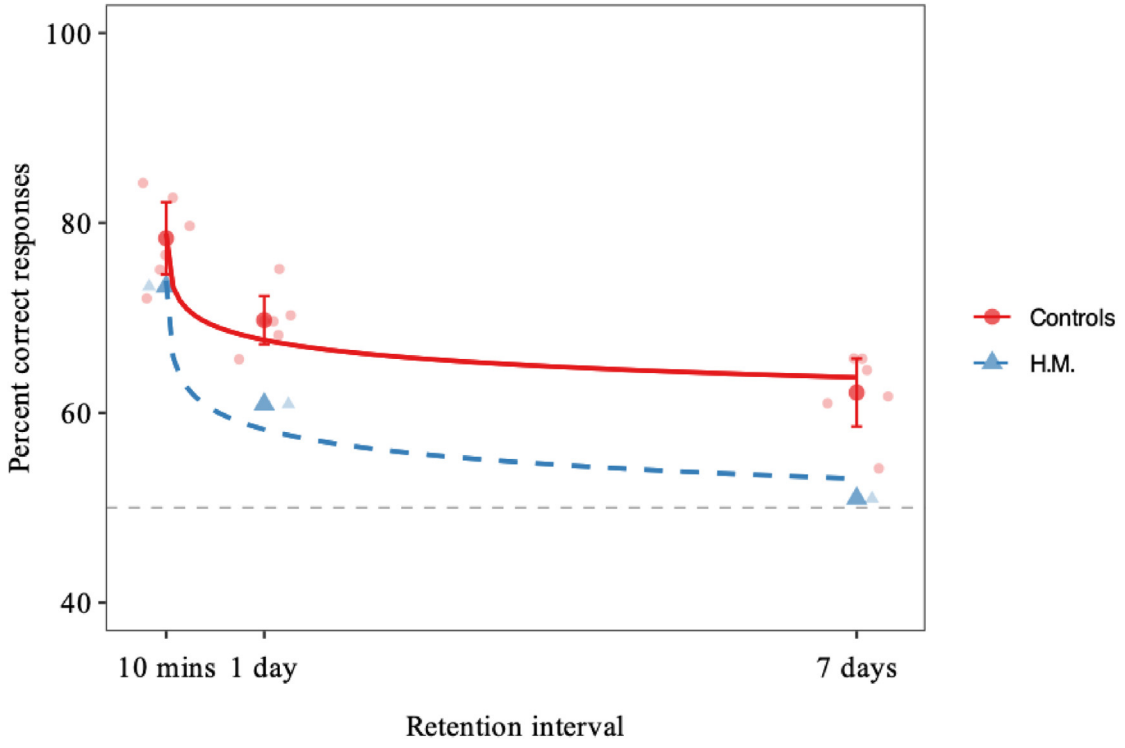

Fig. 1 – Fitted power curves of recognition performance (means ± 2SEs) between H.M. and healthy controls (Huppert & Piercy, 1979).

4. Discussion

The current analysis aims to examine whether H.M. exhibited accelerated long-term forgetting through a direct comparison of yes/no recognition performance between H.M. and healthy controls using the data reported by Huppert and Piercy (1978, 1979) and Freed et al. (1987). During encoding, each participant was presented with 120 slides of coloured pictures. H.M. was allowed for a total of 10 s (Huppert & Piercy, 1979) or 20 s (Freed et al., 1987) to inspect each picture, whereas healthy participants viewed each picture for 1 s. After encoding, yes/no recognition tests were delivered at 10-min, 1-day, and 7-day delays in Huppert and Piercy (1978, 1979) or 10-min, 1-day, 3-day, and 7-day intervals in Freed et al. (1987). Our analyses, using both linear- and nonlinear-based modelling, reconciled the decades-long discrepancy between the findings of Huppert and Piercy (1979) and Freed et al. (1987). The results consistently indicated that H.M. did not exhibit accelerated long-term forgetting compared to healthy controls.

This early debate over whether amnestic patients are subject to fast forgetting has attracted substantial interest in exploring forgetting rates across various amnesic disorders, such as Korsakoff's syndrome (Huppert & Piercy, 1977, 1978; Kopelman, 1985), patients with focal temporal or frontal lobe lesions (Kopelman & Stanhope, 1997), amnestic mild cognitive impairment (De Simone et al., 2022; Lombardi et al., 2018), Alzheimer's disease (Christensen et al., 1998; Kopelman, 1985; Stamate et al., 2020), and psychiatric patients prescribed

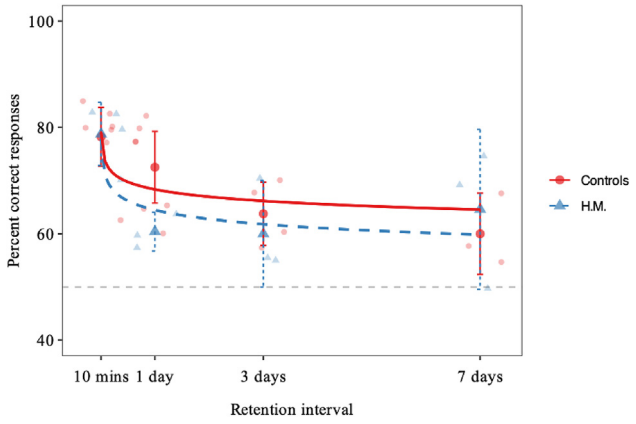

Fig. 2 – Fitted power curves of recognition performance (means ± 2SEs) between H.M. and healthy controls (Freed et al., 1987).

electroconvulsive therapy (Lewis & Kopelman, 1998; Squire, 1981). Provided that pain is taken to minimise the influence of retrieval practice effect (Roediger & Karpicke, 2006; Stamate et al., 2020), the results generally indicated no significant difference in forgetting rates between healthy controls and amnestic patients with focal lesions, mild cognitive impairment, or Alzheimer's disease in terms of recognition performance, as noted in a recent viewpoint by Kopelman (2024). The current analysis of H.M.'s recognition performance aligns with this conclusion.

Given the deficits in acquisition among amnestic patients, the cross-group comparison design typically pursued equal initial performance between patient and control groups. Matching initial learning is beneficial for a straightforward comparison of forgetting rates across groups, therein terminating long-standing debates over the scaling issues in measuring forgetting (Loftus, 1985a, 1985b; Slamecka, 1985) or

Table 2 – The goodness-of-fits, parameter estimates, and model comparisons between unconstrained and constrained models (Huppert & Piercy, 1978, 1979).

Huppert and Piercy (1979)	Goodness-of-fits			Parameter estimates		Model comparisons	
	AIC	*BIC*	R^2	*a (SE)*	*b (SE)*	*F value*	*p value*
Exponential-power: $y = ae^{-b\cdot\sqrt{t}}$							
H.M. (unconstrained)	17.40	14.70	.968	72.89 (2.64)	.004 (.001)	/	/
Controls (unconstrained)	15.10	12.40	.972	78.03 (1.78)	.002 (.001)	10.91	.187
Controls (constrained)				82.13 (3.17)	.004		
Power: $y = at^{-b}$							
H.M. (unconstrained)	18.60	15.90	.953	82.51 (5.41)	.05 (.01)	/	/
Controls (unconstrained)	17.10	14.40	.946	84.68 (4.00)	.03 (.01)	5.48	.257
Controls (constrained)				92.98 (3.68)	.05		
Logarithmic: $y = a - bln(t)$							
H.M. (unconstrained)	17.60	14.90	.967	81.06 (3.96)	3.09 (.57)	/	/
Controls (unconstrained)	16.50	13.80	.956	84.04 (3.31)	2.23 (.48)	3.20	.325
Controls (constrained)				89.41 (2.02)	3.09		

Notes: In these retention equations, y indicated memory performance, *a* represented the initial degree of learning, *b* referred to as the slope of the function, and t was the time.

Table 3 – The goodness-of-fits, parameter estimates, and model comparisons between unconstrained and constrained models (Freed et al., 1987).

Freed et al. (1987)	Goodness-of-fits			Parameter estimates		Model comparisons	
	AIC	*BIC*	R^2	*a (SE)*	*b (SE)*	*F value*	*p value*
Exponential-power: $y = ae^{-b\cdot\sqrt{t}}$							
H.M. (unconstrained)	99.70	101	.296	74.96 (4.58)	.002 (.001)	/	/
Controls (unconstrained)	147	150	.475	79.37 (2.64)	.003 (.001)	.36	.555
Controls (constrained)				78.19 (1.73)	.002		
Power: $y = at^{-b}$							
H.M. (unconstrained)	95.50	97.20	.491	85.08 (6.29)	.04 (.01)	/	/
Controls (unconstrained)	151	154	.382	84.63 (4.57)	.03 (.01)	1.07	.313
Controls (constrained)				88.83 (2.17)	.04		
Logarithmic: $y = a - bln(t)$							
H.M. (unconstrained)	95.70	97.40	.481	83.61 (5.71)	2.59 (.81)	/	/
Controls (unconstrained)	150	153	.389	82.20 (4.18)	2.17 (.62)	.45	.511
Controls (constrained)				86.75 (1.70)	2.59		

absolute versus relative forgetting (Della Sala et al., 2024; Wixted, 2022). This close matching is usually achieved by extending the encoding time and/or increasing the repetitions of to-be-remembered materials (Elliott et al., 2014). If the encoding procedures were not balanced between groups, it would inevitably confound the processes involved in both encoding and retrieval (Mayes, 1986). For instance, in the present studies, healthy participants underwent a total duration of 2 min for encoding, whereas H.M. had 20 min in Huppert and Piercy (1979) and 40 min in Freed et al. (1987). Allowing additional encoding times or multiple presentations would lead individuals to overlearn the materials or develop intentional mnemonic strategies in aid of remembering, potentially clouding the actual changes in retention. In the study by Freed et al. (1987, Fig. 3), H.M.'s average forced-choice recognition (also known as delayed-match-to-sample) was significantly higher than that of healthy participants at both 3-day and 7-day delays. This facilitated performance in H.M. could potentially be attributed to prolonged encoding times and repeated study. Meanwhile, the memory test at the same time interval is actually measuring memories from different ages. According to Jost (1897) second law of forgetting, if two memories are of equal strength but different ages, the older one will decay more slowly over a given period of time than the younger. Thus, the memories measured at each recognition test were older in H.M. than in the healthy controls.

Additional efforts have been made to balance the encoding exposures while ensuring matched initial learning. For instance, to compare forgetting rates in amnestic disorders following temporal lobe, diencephalic, or frontal lobe lesions, Kopelman and Stanhope (1997) included an inter-stimulus filter task at encoding to control the average duration of stimuli-to-test delay across groups. They found no significant differences in forgetting rates for visual and verbal recognition. Similarly, Christensen et al. (1998) employed the same procedure to equate total presentation time and initial performance between patients with Alzheimer's Disease and healthy controls. The results indicated that individuals with Alzheimer's Disease did not exhibit significantly faster rates of forgetting relative to healthy adults on picture recognition.

Our re-analysis revealed that the rate of forgetting in H.M. did not differ from that in healthy controls, regardless of whether the initial performance was matched. This finding is also in concert with one strand of behavioural studies that focused on the relation between the initial degree of learning and rates of forgetting (Bahrick, 1984; McKenna & Glendon, 1985; Meeter et al., 2005; Peng et al., 2024; Rivera-Lares et al., 2022, 2023; Slamecka & McElree, 1983). In these studies, rates of forgetting were compared across varying initial learning performance manipulated during encoding. From the knowledge and skills acquired in educational settings to laboratory materials, including individual words, word pairs, sentences, the rate of forgetting remains constant and is independent of the initial level of acquisition. Collectively, we suggest that the cross-group comparisons in forgetting studies do not necessarily seek a perfect match in initial performance unless the risks of confounding encoding and retrieval processes can be effectively controlled.

Declaration of competing interest

None.

CRediT authorship contribution statement

Nan Peng: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Formal analysis, Data curation. **Umberto Noè:** Writing – review & editing, Validation, Methodology, Data curation. **Sergio Della Sala:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Acknowledgements

In memory of Prof. Felicia Huppert (1945–2024), whose contributions have profoundly accelerated our understanding of human memory and forgetting. We also extend our gratitude to Prof. Michael Kopelman for his constructive feedback on this viewpoint.

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