Manuscript in press at Psychological Science; accepted June 5, 2020

The truth is out there: Accuracy in recall of verifiable real-world events

Nicholas B. Diamond^{1,2,4}, Michael J. Armson^{1,2}, & Brian Levine^{1,2,3}

¹Rotman Research Institute, Baycrest Health Sciences, Ontario, Canada, M6A2E1

²Department of Psychology, University of Toronto, Ontario, Canada, M5S3G3

³Department of Medicine (Neurology), University of Toronto, Ontario, Canada, M5S1A1

⁴Department of Psychology, University of Pennsylvania, PA, USA, 19104

Corresponding authors:

Nicholas B. Diamond: Department of Psychology, University of Pennsylvania, Philadelphia, PA,
USA, 19104; 647-537-5377; diamondn@sas.upenn.edu

Brian Levine: Rotman Research Institute at Baycrest, 3560 Bathurst St, Toronto, Ontario,
Canada, M6A 2E1; 416-785-2500 x.3593; blevine@research.baycrest.org

Abstract

How accurate is memory? Although people implicitly assume that their memories faithfully represent past events, the prevailing view in research is that memories are error-prone and constructive. Yet little is known about the frequency of errors, particularly in memories for naturalistic experiences. Here, younger and older adults underwent complex real-world experiences that were nonetheless controlled and verifiable, freely recalling these experiences after days to years. As expected, memory quantity and episodic detail richness declined with increasing age and retention interval. Details that participants did recall, however, were highly accurate (93-95%) across age and time. This level of accuracy far exceeded comparatively low estimations among memory scientists and other academics in a survey. These findings suggest that details freely recalled from one-time real-world experiences can retain high correspondence to the ground truth despite significant forgetting, with higher accuracy than expected given the emphasis on fallibility in the field of memory research.

Introduction

Episodic memories are not simply stories we tell but rather descriptions of specific past experiences. We implicitly assume that our own memories are accurate (Brewer, 1988), and this assumption guides our decisions and establishes social correspondence (Mahr & Csibra, 2017). On the other hand, memories are not copies of the experiences they represent. Firstly, they are transient – most encoded information is rapidly lost (Ebbinghaus, 1913; Richards & Frankland, 2017). Second, memory is reconstructive, sometimes distorting or augmenting the reality of the past (Bartlett, 1932; Loftus, 2005; Schacter & Addis, 2007).

While the transience of memory has been appreciated for over a century (Ebbinghaus, 1913), more recent experimental evidence for the fallibility of memory has captured the attention of researchers and the general public. Many factors can increase the probability of distortions or outright confabulations in recall, including suggestive cues (Lindsay, Hagen, Read, Wade, & Garry, 2004; for review, see Loftus, 2005), interviewing style (Fisher, McCauley, & Geiselman, 1994) or schema-driven expectations (Brewer & Treyens, 1981). There is now no doubt that recall is vulnerable to contamination by these and other factors, and this vulnerability lies at the heart of influential theories emphasizing memory's constructive and error-prone nature (e.g. Barry & Maguire, 2018; Loftus, 2005; Schacter & Addis, 2007). Yet relatively little is known about accuracy in recall of everyday real-world experiences, where individuals are actively involved in the encoding experience and retrieval is not deliberately influenced by error-producing manipulations.

Because the ground truth of memories for personal real-world events is usually unknown, experimenters devised alternative methodologies for measuring memory accuracy. Diary studies, for instance, sometimes revealed striking examples of distortion (Brewer, 1988; Linton, 1975).

Similarly, flashbulb memories for public and affectively charged events are often vivid and confidently held even when incorrect (Talarico & Rubin, 2003). These findings led some to conclude that autobiographical memories, particularly remote ones, are essentially narratives constructed out of schematic knowledge and inference (Barclay & Wellman, 1986; Barry & Maguire, 2018). Yet diary-recorded events are self-selected for their emotional significance (Brewer, 1988), and flashbulb events are by definition emotionally arousing and are prone to distortion. Critically, neither kind of event is experimentally controlled at the time of encoding, limiting accuracy measurement.

The experimenters' knowledge (or lack thereof) of the objective event details limits the resolution at which memory accuracy can be measured. In lieu of directly measuring the correspondence between recalled and encoded details, researchers often rely on consistency with diary records or initial recall attempts, both of which are likely to be affected by rapid forgetting and to alter subsequent recall attempts. Alternatively, researchers have relied on consistency across individuals' memories of a shared experience (McKinnon et al., 2015) or correspondence with public records (Neisser, 1981). Measures of memory consistency, therefore, are often restricted to relatively few and coarse details that are repeated across individuals or across timepoints. Freely recalled autobiographical memories, on the other hand, routinely contain scores of event-specific, idiosyncratic details from single experiences (Levine, Svoboda, Hay, Winocur, & Moscovitch, 2002). The degree to which these recalled details accord with encoded details remains unknown.

To the extent that memory errors occur, they are thought to increase in older age (Devitt & Schacter, 2016; Diamond, Abdi, & Levine, 2020) and with the passage of time (Armson, Abdi, & Levine, 2017; Barclay & Wellman, 1986). This is consistent with findings that

memories tend to transform from more detailed to more schematic with increasing age and retention interval (Levine et al., 2002; Sekeres et al., 2016). Most of these findings, however, come from forced-response paradigms that confound accuracy with quantity. Accuracy measurement requires participant control over responding and output-bound (what proportion of retrieved items are accurate?) rather than input-bound (what proportion of encoded items are retrieved?) analyses. These two approaches reflect theoretically orthogonal “correspondence” versus “storehouse” conceptions of memory, respectively (Koriat & Goldsmith, 1996).

In the present study, we aimed to quantify accuracy in naturalistic recall using complex and immersive yet verifiable real-world experiences, pairing the experimental control of laboratory encoding paradigms with the ecological validity of autobiographical memory. Younger and older participants freely recalled their experiences after delays of two days to several years. We augmented the widely used Autobiographical Interview scoring system (AI; Levine et al., 2002) to measure, at a fine grain, the output-bound proportion of spontaneous memory errors with reference to the objective event details, and to contrast accuracy with memory detail (i.e. episodic richness) and quantity (i.e. forgetting).

We predicted that output-bound recall accuracy would be high notwithstanding forgetting (loss of quantity), which we expected to increase with aging and the passage of time. In order to relate our results to perceptions of memory accuracy, we conducted a survey of both memory researchers and academics from unrelated fields in which we asked them to predict the results of our study. Given the strong emphasis on fallibility in memory research, we predicted that both experts and non-experts would underestimate the accuracy of memory as measured in this study.

Methods

Participants

Seventy-four participants (see Table 1) took part in one of two controlled real-world events that were assessed as part of a series of studies designed to investigate aspects of memory retrieval not available in standard autobiographical memory paradigms. The first study investigated the effect of retention interval on recognition memory for a respiratory mask fitting procedure (the Mask Fit Test) in 135 hospital employees (Armson et al., 2017). A subset of 33 of these younger participants ('MaskFit-Y' in the present study) freely recalled the Mask Fit Test prior to recognition testing using the Autobiographical Interview (AI; Levine et al. 2002; not included in Armson et al., 2017). The second study was designed to compare recognition memory for naturalistic vs. laboratory versions of the same event, an audio-guided art tour of Baycrest Hospital, in 84 younger and older adults with little or no previous exposure to Baycrest Hospital (Diamond, Abdi, & Levine, 2020; we designate this event Baycrest Tour 1.0, as distinguished from different tours used in subsequent studies). Free recall of the tour was collected for participants in the naturalistic arm of this study ($N = 41$; 'Tour-Y' and 'Tour-O' in the present study). These free recall protocols are also analyzed in a separate report concerning temporal contextual dynamics in free recall (Diamond & Levine, *in revision*). All participants were screened for history of neurological disease, active significant medical or psychiatric illness or consumption of medication that may affect memory, or active or recent substance abuse. These studies were approved by Baycrest's research ethics board. For additional details, see Supplementary Material.

Table 1. Demographic data and remoteness for the three encoding condition groups (Y = younger, O = older). Note that all Mask Fit Test participants were younger; the ‘Y’ designation is for consistency with the Tour group labels.

Group	N	Age (years)	Education (years)	Retention interval (days)
Mask Fit Test (MaskFit-Y)	33 (24 women)	$M = 26.64$, $SD = 6.27$, range = 18-41	$M = 17.58$, $SD = 3.33$	$M = 267.03$, $SD = 278.98$, range = 29-1243
Baycrest Tour Younger (Tour-Y)	22 (14 women)	$M = 23.82$, $SD = 3.92$, range = 19-35	$M = 15.64$, $SD = 1.09$	2
Baycrest Tour Older (Tour-O)	19 (15 women)	$M = 69$, $SD = 3.07$, range = 65-75	$M = 16.53$, $SD = 3.63$	2

Since these data were not collected specifically for the questions in this study, we did not conduct an *a priori* power analysis. Our first main question was descriptive: how accurate is recall of real-world experiences, given the encoding and recall conditions used in this study? Though the necessary sample size for this is unclear, the stability of our finding is supported by attaining similar estimates across two different events with independent samples ($N=33$ and $N=41$). Our second main question was about the relation between our empirical accuracy measurements and estimations of memory accuracy among memory scientists ($N = 54$) and education-matched academics in unrelated fields ($N = 326$).

The Event Encoding Conditions

The Mask Fit event

The Mask Fit Test is a unique, complex and highly stereotyped procedure mandated for all employees at Baycrest Health Sciences (see Figure 1A). The test is a provincially-mandated standardized procedure instituted after the 2003 Severe Acute Respiratory (SARS) outbreak. The

purpose of the test is to identify properly fitted respiratory masks for all hospital employees. It is temporally extended and rich in multisensory detail while also being highly scripted – everyone is exposed to the same test elements, in the same order, in the same spatial context and by the same technicians – making it useful as a naturalistic staged event for memory assessment. The procedure includes spraying a bitter solution on each participant’s tongue to ensure taste sensitivity, donning a respiratory mask and a large white fume hood, spraying the bitter solution into the fume hood, reading a passage aloud, and making a series of head and body motions (Armson et al., 2017; see Supplemental Table S1 for list of all recalled details from the Mask Fit event). As MaskFit-Y participants were recruited to the study weeks-to-years after the event, encoding was fully incidental. We note that past memory studies have used medical procedures as staged events with testing at long delays, particularly in children (e.g. Ornstein, Baker-Ward, Gordon, & Merritt, 1997).

The Tour Event

The Baycrest Tour event involved a prospectively designed real-world walking tour of the first floor of Baycrest Hospital, guided by a museum-style audio guide (see Figure 1B). The audio guide controlled the target content, item order (which was also dictated by the track-like physical layout), and encoding duration for each item. It is publicly available on the Open Science Framework (<https://osf.io/pmt7d/>). The first floor of Baycrest is visually rich and contains many art pieces, exhibits, and architecturally distinct areas. The tour route formed a loop through several different sections of the building. Although participants were instructed to approach different target items, the tour route was generally unidirectional. Participants were instructed to examine different target items (e.g. paintings, portraits, and exhibits) and complete

different tasks (e.g. locate a particular individual in a frame of portraits, or locate a particular item in the gift shop) (See Supplemental Table 2 for list of all recalled details from the Tour event) (Fig. 1B). Part way through the tour, participants had an interaction with a research confederate, during which the confederate asked a series of scripted questions. This served to create more recallable content, and to increase the self-referential and engaging nature of the tour. Participants were unobtrusively monitored by the experimenter during the tour to confirm consistency of the protocol across participants. For full details of the events, see the Supplementary Material.

A

"Now we will put on the N95 mask"

"Can you taste the solution now?"

"Please read the 'rainbow passage'"

...

...

*Int - place - inaccurate **

Int - place - accurate

"...that was **on the second floor** of the **building next to this one** and there was **one**

Int - event - accurate *Int - percept. - accurate* *Int - percept. - unconfirmable*

male instructor, middle aged, and four or five other people were there. I don't

Ext - other

Int - percept. - accurate

Int - event - accurate

remember the order but...The room was rectangular and I was sitting here, the

Int - percept. - accurate

Int - percept. - unconfirmable

entrance was on my right side and all other people were sitting on the left side of

*Int - percept. - inaccurate ***

me. There was a window in that room....

Figure 1. Schematics of the two event encoding conditions and example recall excerpts with detail and accuracy coding. (A) Top: Depiction of four of the scripted components in the MaskFit procedure (event MaskFit-Y). Bottom: Recall excerpt for event MaskFit-Y. Detail and accuracy scoring codes (in colour) are overlaid above the recall text (in black). The first field in each code identifies the detail as internal (Int) or external (Ext). The second field is the detail type (*event*, *perceptual* (*percept.*), *place*, *time*, or *emotion/thought*). The third field is the accuracy score (*accurate*, *inaccurate*, or *unverifiable*). *the MaskFit-Y event did not take place on the second floor ('other' error); **there was no window in the room ('perceptual error'). (B) Top: Map of

Baycrest's ground floor showing the tour route and three example photographs of the 27 target items (Tour event [Baycrest Tour 1.0]). *Bottom*: Recall excerpt from a Tour-Y participant.

****the market was on the participant's right ('perceptual error'); ***the ceramic chef was not holding a cake lift ('semantic error').*

Procedure

Autobiographical Interview administration and scoring

The Autobiographical Interview (AI; Levine et al., 2002) is a standardized semi-structured interview and accompanying scoring method for quantifying the detail composition of memory narratives. During the AI, participants freely recalled the event (Mask Fit Test or Baycrest Tour; "Tell me everything you can remember about ____"), followed by general probes as needed to clarify instructions (e.g., "Is there anything else you can tell me about this event?"), followed by a structured specific probe procedure (administered after all events have been tested with free recall and general probe). This specific probe was originally intended to elicit details in people with memory impairment and therefore gives latitude to the examiner to probe for additional content in a manner that varies across subjects according to details produced during free recall. We therefore restricted our analyses to free recall and general probe, which were administered in a consistent manner across participants (for full details about the AI administration and scoring, see the Supplementary Material and previous studies; e.g. Levine et al., 2002).

Memories were audio-recorded and then transcribed. Trained scorers segmented memories into component clauses expressing discrete details, each of which was classified as internal (specific in place and time to the target event; episodic) or external (not spatiotemporally

specific to the target event, semantic/factual, repetition, metacognitive or other). Internal details and non-specific external details were sub-classified as event, place, time, perceptual or thought/feeling. Concerning memory detail, our measure of interest was the internal/total detail proportion, reflecting the richness or density of event-specific details in a memory while adjusting for individual differences in verbosity and event differences in content and duration.

Quantity Scoring

Internal detail counts can provide a rough proxy of memory quantity, but they do not speak to how much was *not* recalled (i.e. forgotten). Quantity of recall was characterized as the percentage of total verifiable details recalled by each participant (see below for explanation of verifiable details). This measure is distinct from the counts of verifiable and internal/external details reported above that were tallied within each participant without reference to an objective total number of encoded details. Such a total is required to serve as a denominator indicating what was encoded, analogous to the total number of stimuli in a list in a classic laboratory recall paradigm.

Given the complexity of real-world episodes and individual differences in narrative-style free recall, it is impossible to objectively establish the ‘true’ number of discrete bits of information encoded and recalled across sample of individuals. As a proxy of this measure, for each event, we created corpuses of all unique verifiable details recalled across all participants (assimilating details that were sufficiently similar notwithstanding individual differences in word use), along with the identity of participants who recalled them (see Supplementary Tables S1 and S2 for corpuses and recall counts; for a similar approach, see McKinnon et al., 2015). We considered any detail that referred to a verifiably universal event feature and that was recalled by

more than one person to be one that could have reasonably been encoded by every participant. The resulting corpuses contained 61 details for the Mask Fit event and 209 details for Tour event. Detail coding was manualized by N.B.D. and scored by the full team of AI scorers. We then returned to the individual protocols and counted the number of corpus details recalled, then divided this sum by the total number of details in the corpus for the identified event. This procedure enabled comparison of memory quantity across participants who experienced the same event.

Accuracy Scoring

Figure 2 presents a schematic of the accuracy scoring procedure. Following standard AI scoring, the accuracy of transcribed memories was assessed with our novel scoring system that leverages the experimental control provided by staged event encoding conditions (for similar procedures, see e.g. Dede, Frascino, Wixted, & Squire, 2016; Evans & Fisher, 2011; McKinnon et al., 2015). By definition, only internal details were amenable to accuracy scoring. Internal details were first deemed verifiable or unverifiable, depending on whether they pertained to any objectively verifiable elements of the events. For example, details about stable features of the environment (e.g. colours of walls or paintings, sizes of rooms or objects, locations, etc.) and actions or event features (e.g. looking at a given painting, relative timing, etc.) that were controlled by the event administrator (i.e. standardized protocol for Mask Fit and the audio guide for Baycrest Tour) were universal for all participants and therefore verifiable. Some non-universal or time-varying details (e.g. the time on the clock during a given participant's tour) could be verified by reference to testing notes recorded by the administrator at the time of encoding. Any internal details that were unobservable or idiosyncratic (not universal) and

undocumented are unverifiable. Thoughts are by definition unverifiable. On average, MaskFit-Y participants produced 23.93 ($SD = 12.74$) verifiable details (M internal detail count = 33.64, M proportion verifiable = .70), Tour-Y participants produced 79.68 ($SD = 38.04$) verifiable details (M internal detail count = 92.45, M proportion verifiable = .88), and Tour-O participants produced 52.05 ($SD = 46.18$) verifiable details (M internal detail count = 69.58, M proportion verifiable = .63). As expected, age was associated with decreases in the extent to which episodic details reflected objective and verifiable elements of the events (see Supplementary Material for analysis of verifiable details). Overall, all three groups produced many internal details, the majority of which were verifiable and thus amenable to accuracy scoring.

Figure 2. Schematic of the accuracy scoring procedure, ordered from top to bottom.

Accurate and inaccurate details include any verifiable details that are true or false, respectively. Thus, every internal detail was scored as either accurate (A), inaccurate (I) or unverifiable (U). Inaccurate details were classified according to error type (sequence, labelling, perceptual, semantic, other, or recognition-cued [for Tour groups only]) (See Fig. 1 and Supplementary Material for descriptions and examples of error types).

Data Analysis

Data were analyzed using the R programming language. We tested group differences using ANOVAs, where appropriate. To test pairwise group difference, we used Welch's t -tests to account for unequal variances across groups, rounding the degrees of freedom to the nearest whole number, with Bonferroni-corrected p values unless otherwise noted. We report Cohen's d effect sizes and Pearson correlations with 95% confidence intervals (CIs). All statistical tests two-sided.

Results

Internal versus External Details

We first examined the effects of group (Mask Fit Test [MaskFit-Y], Tour younger [Tour-Y], and Tour older [Tour-O]) on detail type (internal [episodic] vs. external [non-episodic]) to determine if established findings in autobiographical memory for self-selected events generalize to the controlled encoding paradigms used here. We found a significant interaction between group and detail type ($F(2,71) = 22.77, p < .001$) (Fig. 3). In keeping with prior aging research, the Tour-Y group had significantly higher internal:total detail ratios than the Tour-O group ($t(24) = 3.92, p = .002, d = 1.29, 95\% \text{ CI } [0.60, 1.99]$). Higher internal:total detail ratios for the Tour-Y versus MaskFit-Y groups ($t(52) = 2.98, p = .013, d = .74, 95\% \text{ CI } [.17, 1.31]$) was consistent with a recency effect such that more recent events are recollected in greater detail than more remote events, although we cannot rule out the possibility that this finding was driven by other differences between the Mask Fit and Tour events. Similarly, we observed a significant negative correlation between retention interval and internal detail proportion within the MaskFit-Y sample ($r(31) = -.42, 95\% \text{ CI } [-.08, -.66], p = .016$) (Fig. S2B), although caution is warranted in

interpreting this effect due to the small sample size. For full details and analysis of internal detail types, see the Supplementary Material.

Figure 3. Raw internal and external detail counts. Black circles with white fill indicate group means. Error bars indicate the standard error of the mean. Smaller coloured dots depict individual participants, and are slightly horizontally jittered to reveal overlap.

Memory Quantity

To measure recall quantity, for each event, we created a corpus of every unique, verifiable, and accurate detail that was recalled by at least two participants, and then counted how many of these details were recalled by each participant (see Methods and Supplementary Material). There were 209 details in the corpus from the Tour event, and 61 from the Mask Fit event (See Supplementary Tables S1 and S2 for full lists of all details in each corpus and the number of participants who recalled them). This disparity between events is consistent with their different recency and complexity, and greater experimental control – and thus a higher

proportion of verifiable details – in the Tour event. Given these differences, quantity scores should not be directly compared across the Mask Fit and Tour events. MaskFit-Y participants recalled on average 23.75% ($SD = 10.5\%$) of corpus details, Tour-Y participants recalled 21.18% ($SD = 8.8\%$) and Tour-O participants recalled 14.63% ($SD = 10.6\%$) (Fig. S4). Among Tour participants, there was a significant negative effect of age ($t(35) = 2.13, p = .040, d = .68, 95\%$ CI [.03, 1.34]). Among MaskFit-Y participants, recall quantity was negatively correlated with retention interval ($r(31) = -.43, 95\%$ CI [-.10, -.67], $p = .014$) (Fig. S2C), declining in curvilinear fashion as a function of time, as expected (Ebbinghaus, 1913; Rubin & Schulkind, 1997).

Younger participants, therefore, recalled roughly 1/5th to 1/4th of all unique verifiable details, and this number declined with both age and retention interval. Our proxy measure for quantifying the number of encoded details almost certainly underestimates the true number of encoded details, so these results likely reflect an upper bound on memory quantity.

Memory Accuracy

We calculated accuracy as the output-bound proportion of verifiable internal details that were accurate with respect to the objective features of the events and the environments in which they were embedded. Mean accuracy proportions were uniformly high, ranging from .93 ($SD = .06$) in the Tour-O group to .95 ($SD = .06$) in the MaskFit-Y group (Tour-Y: $M = .94, SD = .04$). One-sample t-tests confirmed that accurate detail proportion was significantly off ceiling in each group (p 's < .001, d 's > .85). On the other hand, we detected at least one error in 56 out of 74 participants (75.68%), and two errors or more in 34 participants (45.95%), suggesting that our accuracy analysis was sensitive to errors. Types of errors did not significantly vary by group (see Supplementary Material, Fig. S1).

We ran a one-way ANOVA modelling the effect of group on accuracy. In contrast to our observations of group differences in internal versus external details and verifiable details, we found no significant difference in accuracy ($F(2,71) = .49, p = .615$) (Fig. 4). Post-hoc non-parametric pairwise group comparisons (Mann-Whitney U-tests), conducted due to non-normal distributions within each group, also did not reveal group differences (p 's $> .3$, uncorrected). Indeed, Bayesian two-sample t -tests suggested that the groups did not differ in recall accuracy (BF_{01} 's = 2.49 – 3.31). Similarly, accuracy did not decline with retention interval in the MaskFit-Y sample ($r(30) = -.19$, 95% CI $[-.50, .17]$, $p = .303$, $BF_{01} = 1.63$; see Fig. S2D). Although Bayes Factors lower than 3 indicate at best anecdotal evidence for the null hypothesis, these findings together provide no evidence for group or time-related effects on recall accuracy.

Therefore, despite changes in the quantity and detail of memory with increasing retention interval and age, we did not observe a concomitant decline in the accuracy of retrieved details. The absence of group differences in accuracy may have been affected by restriction of range and therefore should be interpreted with caution. Nonetheless, it is clear from these data that participants made few errors (as a proportion of output) in their recall of these events.

Figure 4. Accuracy as a proportion of verifiable internal details in each group.

Survey of beliefs about memory accuracy

To empirically gauge general impressions about memory accuracy in the memory field and beyond, we polled memory scientists' and other academics' estimations of free recall accuracy, describing encoding and retrieval conditions mirroring those in our current study. We solicited separate estimates of memory quantity (how much of the encoded content would be recalled) and memory accuracy (of recalled information, what proportion would be accurate) to ensure that these were not confused (see below for full instructions). Accuracy was framed as the proportion of all freely recalled details that are accurate, and these estimates can therefore be compared to our empirical accuracy data. Beliefs about memory quantity, on the other hand, are

harder to relate to our empirical data because the notion of memory quantity is less clear, and because we empirically measured quantity as a proportion of all details recalled by two or more participants.

Survey Methods

Memory scientists (N = 68; Master's = 2, PhD = 28, Postdoc = 17, PI/Professor = 14, other = 3) were recruited at academic memory talks and conferences in 2018, in person and via social media. They completed the survey online via the Qualtrics platform (www.qualtrics.com). They were screened for familiarity with the authors' work on this topic. Academics in fields unrelated to memory (N = 350; Master's = 54, PhD = 148, Postdoc = 13, Professor/faculty member = 107, other = 28) were recruited via email from graduate departments (excluding those related to psychology or cognitive neuroscience) at the University of Toronto. 19 of these participants were excluded for estimating '0-10%' for all four survey questions (see below). Participants who failed to respond to all questions were also excluded.

The instructions were as follows:

“Imagine the following scenario: A healthy 30 year-old adult attends an audio-guided museum tour as part of a memory experiment. Memory for the tour is tested using free recall (i.e., the person says everything they can remember about the event) 48 hours later. For the following questions, an “encoded detail” is a discrete bit of information that the participant heard and/or saw (e.g., a painting of a yellow sailboat). It does not refer to incidental or irrelevant information that was not attended (e.g., the floor tile was

black). “Accurate” refers to the factual correctness of recalled details (e.g., “a painting of an orange sailboat” would be incorrect, if the sailboat was in fact yellow).

- 1) What **proportion of encoded details** would be freely recalled after 48 hours?
- 2) What proportion of these freely recalled details would be **accurate** after 48 hours?”.

Participants indicated their responses by clicking one of 10 options: 0-10%, 10-20%, 20-30%, 30-40%, 40-50%, 50-60%, 60-70%, 70-80%, 80-90%, 90-100%. They were then asked the same questions, but with an imagined healthy 70 year-old adult participant. These questions were then repeated, with the following instruction:

“Now, imagine the same scenario, but memory for the tour is tested (again using free recall) **two years** later”.

Note that we used the imagined two year delay in the survey as a simplified stand-in for the whole range of actual delays in the Mask Fit (range: 29-1243 days).

Survey Results

Accuracy estimates were low – median estimated accuracy under the ‘best’ of the theoretical conditions (a younger participant at a 48 hour delay) was 40% (mean = 41.3%) among memory scientists and 30% (mean = 36.7%) among other academics, indicating that over half of freely recalled details would be inaccurate. There was no significant difference in overall accuracy estimates made by memory experts versus other respondents ($F(1,378) = 2.73, p = .099$). Compliance with survey instructions was supported by expected effects of the imagined participant’s age ($F(1,378) = 172.49, p < .001$) and retention interval ($F(1,378) = 315.59, p <$

.001) on recall accuracy. Estimates were higher for an imagined 30 year-old versus a 70 year-old (paired Wilcoxon signed-rank test, $V = 2642$, $p < .001$), and for 48 hours versus 2 years ($V = 1790$, $p < .001$) (Fig. 5). These survey results, in conjunction with our findings, support Koriat et al.'s (2000) assumption that views of human memory accuracy are overly pessimistic. This is true of both memory scientists and other education-matched academics. The survey data about memory quantity are included for completeness in the Supplementary Material (Fig. S5).

Figure 5. Estimates of memory accuracy made by memory scientists ($N = 54$; Master's = 5, PhD = 24, Postdoc = 11, PI/Professor = 11, other = 3; see Methods) and academics in fields unrelated to memory ($N = 326$; Master's = 50, PhD = 138, Postdoc = 10, Professor/faculty member = 102, other = 26). Participants were instructed to imagine that a healthy 30-year-old (*left*) and a healthy 70-year-old (*right*) took part in an audio-guided museum tour as part of a memory experiment,

and that memory for the tour would be tested using free recall. They were asked to estimate (1) the proportion of encoded details that would be freely recalled (see Methods) and (2) the proportion of freely recalled details that would be accurate, after 48 hours (*top*) and after two years (*bottom*).

Discussion

We combined controlled real-world encoding paradigms with a novel recall coding system to measure accuracy in naturalistic event recall at the level of single details, and contrast it with measures of memory quantity and detail. Participants spontaneously and reliably recalled dozens of unique event-specific details (with many recalling 100 or more), most of which were verifiable. On the other hand, these details comprised less than one quarter of encoded details, highlighting that the majority of information making up our experiences is forgotten or omitted from subsequent free recall. Despite age- and time-related declines in episodic detail richness and memory quantity, accuracy was high (93-95% of verifiable details) in all groups. This suggests that memory for remote (days- to years-old) real-world episodes is more accurate than expected, as confirmed by our survey of intuitions about recall accuracy, where the modal predicted error rate was greater than 50%.

Similarly high output-bound accuracy rates in free recall can be seen (though often not discussed), in standard laboratory recall studies, even those highlighting false memory (e.g. see discussion of Deese-Roediger-McDermott paradigm in Koriat, Goldsmith, & Pansky, 2000). The present results extend these findings to copiously detailed descriptions of real-world experiences recalled up to years later. It is noteworthy that we detected at least one error in the majority of participants. Thus, though infrequent, recall errors do occur under naturalistic encoding and free

recall conditions, although it is difficult to identify when errors stem from erroneous mnemonic representations versus spontaneous language use. Our finding that accuracy was robust to increasing retention interval and age stands in contrast to forced-choice recognition memory studies of both laboratory and real-world events, where both factors are associated with increases in susceptibility to false alarms (Armson et al., 2017; Barclay & Wellman, 1986; Devitt & Schacter, 2016; Diamond et al., 2020).

With respect to retention interval, the present results are consistent with previous studies showing high output-bound accuracy for naturalistic content after delays of weeks to years (Ebbesen & Rienick, 1998; Poole & White, 1993). But whereas initial event-proximal recall attempts likely enhanced or otherwise altered subsequent memory in these studies, our participants performed free recall for the first time days-to-years after their experiences, and among Mask Fit Test participants, encoding was fully incidental. Our findings parallel eyewitness memory studies showing that forced-response accuracy declines with time, as expected, but free recall and high confidence recognition remain overwhelmingly accurate (Evans & Fisher, 2011; Wixted, Read, & Lindsay, 2016). In free recall, participants spontaneously filter out low-confidence information and adjust the “grain size” of memory reports over time, prioritizing accuracy at expense of detail (Goldsmith, Koriath, & Pansky, 2005). Accordingly, accuracy was high in spite of low proportion of recalled information (relative to the estimated possible encoded information), and it remained stable in spite of the further reductions in quantity and detail with age and time.

The effects of age on episodic detail richness parallel those observed with self-selected autobiographical memories (Levine et al., 2002), bolstering interpretations of age group differences in AI internal details as pertaining to memory processes or representations as

opposed to extraneous factors like event selection. While sensitivity to age differences in accuracy may have been reduced by ceiling effects, we note that accuracy scores were significantly off ceiling in all three groups. Given the number of verifiable details recalled and the detection of at least one error in most participants, there was ample opportunity for more errors to occur. Our accuracy analysis was necessarily limited to event details that could be verified, which made up a smaller proportion of older versus younger adults' recall narratives. The remaining details pertained to internal states (thoughts and feelings) or other unverifiable parts of the tour, such as transient environmental features. While the accuracy of these details is unknown, we see no reason to expect that it would be lower than verifiable detail accuracy. As our sample was composed of healthy older adult volunteers up to age 75, we acknowledge that these results may not generalize to those who are older or those with age-related disorders affecting memory.

Both events in the present study were more novel and distinctive than most everyday experiences, likely reducing the potential for memory conjunction errors (Devitt, Monk-Fromont, Schacter, & Addis, 2016), 'wrong event' errors (Brewer, 1988), or other sources of false memory. Relatedly, the memories under examination here were likely less vulnerable to contamination by group discussion or multiple retellings than more personally significant or social experiences (Marsh, 2007). The events used in this study are not meant to generalize to all everyday events, but rather to capture low-level features characteristic of everyday events. Many previous findings of retrieval distortions have used pseudo-naturalistic narrative material such as stories or movie clips. It is possible that such materials, being more passively encoded and thematic than everyday experiences, may in fact exaggerate the degree to which memory is warped by schemata and expectation. Moreover, passive laboratory encoding conditions produce

more false alarms than real-world experiences even with identical delays and testing procedures (Diamond et al., 2020).

These findings bear on general theories about the nature of episodic memory. Recent literature has emphasized that idiosyncratic details of one-shot experiences are rapidly lost (Misra, Marconi, Peterson, & Kreiman, 2018; Richards & Frankland, 2017), rendering remote episodic autobiographical memories highly or entirely reconstructed (Barry & Maguire, 2018). While malleability and transience are likely costs of a flexible and future-oriented memory system (Richards & Frankland, 2017; Schacter & Addis, 2007), the converse selective pressures on memory storage and accuracy often go unacknowledged. Our findings, while not suggesting that episodic memories are high-fidelity copies of the experiences they represent, are consistent with the notion that levels of detail and accuracy in episodic memory are often strikingly high under unexceptional encoding conditions (Alba & Hasher, 1983; Bainbridge, Hall, & Baker, 2019; Brady, Konkle, Alvarez, & Oliva, 2008). The degree of correspondence between memory and reality is a function of encoding and retrieval conditions, as well as the goals of the rememberer (Koriat et al., 2000). Anecdotally, we observed errors in relation to event elements that were confusable or recalled with many details, though we can only speculate about the causes of such errors as event features were not experimentally manipulated. While the present study focused on the content of recall, we did not assess the degree to which the sequence of freely recalled details corresponded to the encoded sequence of events. In a separate study, we found that such recall dynamics (previously assessed with word lists) can be reliably measured in real-world event recall, and that these are sensitive to aging (Diamond & Levine, 2020). Future studies could test theories of false remembering derived from laboratory studies in naturalistic contexts by combining the staged event method with manipulations at encoding (e.g., by altering

the confusability of events) or retrieval (e.g., induction or probing to elicit more details; see also St. Jacques & Schacter, 2013), or by comparing patient groups with detail generation vs. output monitoring deficits.

The fact that memory is subject to contamination under certain circumstances does not make memory inherently unreliable (Brewin, Andrews, & Mickes, 2020; Wixted, Mickes, & Fisher, 2018). The conflation of these two issues is understandable given the potentially catastrophic consequences of memory errors in some scenarios, and the utility of errors for revealing underlying memory mechanisms. Responses to our survey suggest that memory researchers and other academics indeed estimate recall to be highly unreliable under encoding and free recall conditions matching those used here (see Brewin, Li, Ntarantana, Unsworth, & McNeilis, 2019, for related survey data). The perception that memory is generally inaccurate has important consequences, particularly in relation to court testimony. The present data are consistent with the view that laboratory evidence of memory errors may have led to an “overcorrection” in views of memory accuracy (see Wixted et al., 2018 and associated commentaries; see also Brewin, Andrews, & Mickes, 2020; Koriat et al., 2000). Overall, our findings suggest that the details produced in freely recalled narrative descriptions of past experiences are highly accurate, and they remain accurate as memory quantity and change.

References

- Alba, J. W., & Hasher, L. (1983). Is memory schematic? *Psychological Bulletin*, 93(2), 203–231.
<https://doi.org/10.1037/0033-2909.93.2.203>
- Armson, M. J., Abdi, H., & Levine, B. (2017). Bridging naturalistic and laboratory assessment of memory: the Baycrest mask fit test. *Memory*, 25, 1–10. <https://doi.org/10.1080/09658211.2016.1241281>
- Bainbridge, W. A., Hall, E. H., & Baker, C. I. (2019). Drawings of real-world scenes during free recall reveal detailed object and spatial information in memory. *Nature Communications*, 10(1), 5.
<https://doi.org/10.1038/s41467-018-07830-6>
- Barclay, C. R., & Wellman, H. M. (1986). Accuracies and inaccuracies in autobiographical memories. *Journal of Memory and Language*, 25(1), 93–103. [https://doi.org/10.1016/0749-596X\(86\)90023-9](https://doi.org/10.1016/0749-596X(86)90023-9)
- Barry, D. N., & Maguire, E. A. (2018). Remote Memory and the Hippocampus: A Constructive Critique. *Trends in Cognitive Sciences*, xx, 1–15. <https://doi.org/10.1016/j.tics.2018.11.005>
- Bartlett, F. (1932). *Remembering: A study in experimental and social psychology*. *Remembering: A study in experimental and social psychology*. Cambridge, England: University Press.
- Brady, T. F., Konkle, T., Alvarez, G. a, & Oliva, A. (2008). Visual long-term memory has a massive storage capacity for object details. *Proceedings of the National Academy of Sciences of the United States of America*, 105(38), 14325–14329. <https://doi.org/10.1073/pnas.0803390105>
- Brewer, W. F. (1988). Memory for randomly sampled autobiographical events. *Remembering Reconsidered: Ecological and Traditional Approaches to the Study of Memory*, 21–90.
<https://doi.org/10.1017/CBO9780511664014.004>
- Brewer, W. F., & Treyens, J. C. (1981). Role of schemata in memory for places. *Cognitive Psychology*, 13,

2077230.

Brewin, C. R., Andrews, B., & Mickes, L. (2020). Regaining Consensus on the Reliability of Memory.

Current Directions in Psychological Science, 1–5. <https://doi.org/10.1177/0963721419898122>

Brewin, C. R., Li, H., Ntarantana, V., Unsworth, C., & McNeilis, J. (2019). Is the public understanding of memory prone to widespread “myths”? *Journal of Experimental Psychology: General*.

<https://doi.org/10.1037/xge0000610>

Dede, A. J. O., Frascino, J. C., Wixted, J. T., & Squire, L. R. (2016). Learning and remembering real-world events after medial temporal lobe damage. *Proceedings of the National Academy of Sciences*,

201617025. <https://doi.org/10.1073/pnas.1617025113>

Devitt, A. L., Monk-Fromont, E., Schacter, D. L., & Addis, D. R. (2016). Factors that influence the generation of autobiographical memory conjunction errors. *Memory*, 24(2), 204–222.

<https://doi.org/10.1080/09658211.2014.998680>

Devitt, A. L., & Schacter, D. L. (2016). False memories with age: Neural and cognitive underpinnings.

Neuropsychologia, 91, 346–359. <https://doi.org/10.1016/j.neuropsychologia.2016.08.030>

Diamond, N. B., Abdi, H., & Levine, B. (2020). Different patterns of recollection for matched real-world and laboratory-based episodes in younger and older adults. *Cognition*, 202, 104309.

<https://doi.org/10.1016/j.cognition.2020.104309>

Diamond, N. B., & Levine, B. (2019). Linking details to temporal context reinstatement in recall of real-world experiences. *PsyArxiv*, 1–41.

Ebbesen, E. B., & Rienick, C. B. (1998). Retention Interval and Eyewitness Memory for Events and Personal Identifying Attributes. *Journal of Applied Psychology*, 83(5), 745–762.

<https://doi.org/10.1037/0021-9010.83.5.745>

Ebbinghaus, H. (1913). *Memory: a contribution to experimental psychology*. Teachers. Teachers College.

Columbia University, New York: Columbia University.

Evans, J. R., & Fisher, R. P. (2011). Eyewitness memory: Balancing the accuracy, precision and quantity of information through metacognitive monitoring and control. *Applied Cognitive Psychology*, 25, 501–508.

Fisher, R., McCauley, M., & Geiselman, R. (1994). Improving eyewitness testimony with the Cognitive Interview. In D. F. Ross, J. D. Read, & M. P. Toglia (Eds.), *Adult eyewitness testimony: Current Trends and Developments*. New York: Cambridge University Press.

Goldsmith, M., Koriat, A., & Pansky, A. (2005). Strategic regulation of grain size in memory reporting over time. *Journal of Memory and Language*, 52(4), 505–525.

<https://doi.org/10.1016/j.jml.2005.01.010>

Koriat, A., & Goldsmith, M. (1996). Memory metaphors and the real-life/laboratory controversy: Correspondence versus storehouse conceptions of memory. *Behavioral and Brain Sciences*, 19(02), 167. <https://doi.org/10.1017/S0140525X00042114>

Koriat, A., Goldsmith, M., & Pansky, A. (2000). Toward a psychology of memory accuracy. *Annual Review of Psychology*, 51, 481–537.

Levine, B., Svoboda, E., Hay, J. F., Winocur, G., & Moscovitch, M. (2002). Aging and autobiographical memory: Dissociating episodic from semantic retrieval. *Psychology and Aging*, 17(4), 677–689.

<https://doi.org/10.1037//0882-7974.17.4.677>

Lindsay, D. S., Hagen, L., Read, J. D., Wade, K. A., & Garry, M. (2004). True photographs and false

- memories. *Psychological Science*, 15(3), 149–154. <https://doi.org/10.1111/j.0956-7976.2004.01503002.x>
- Linton, M. (1975). Memory for real-world events. In D. A. Norman & D. E. Rumelhart (Eds.), *Explorations in cognition* (pp. 376–404). San Francisco: Freeman & Company.
- Loftus, E. F. (2005). Planting misinformation in the human mind: A 30-year investigation of the malleability of memory. *Learning & Memory*, 12(4), 361–366. <https://doi.org/10.1101/lm.94705>
- Mahr, J., & Csibra, G. (2017). Why do we remember? The communicative function of episodic memory. *Behavioral and Brain Sciences*, 1–93. <https://doi.org/10.1017/S0140525X17000012>
- Marsh, E. J. (2007). Retelling is not the same as recalling: Implications for memory. *Current Directions in Psychological Science*, 16(1), 16–20. <https://doi.org/10.1111/j.1467-8721.2007.00467.x>
- McKinnon, M. C., Palombo, D. J., Nazarov, A., Kumar, N., Khuu, W., & Levine, B. (2015). Threat of death and autobiographical memory: A study of passengers from flight AT236. *Clinical Psychological Science*, 3(4), 487–502. <https://doi.org/10.1177/2167702614542280>
- Misra, P., Marconi, A., Peterson, M., & Kreiman, G. (2018). Minimal memory for details in real life events. *Scientific Reports*, (October), 1–11. <https://doi.org/10.1038/s41598-018-33792-2>
- Neisser, U. (1981). John Dean's memory: A case study. *Cognition*, 9(1), 1–22. [https://doi.org/10.1016/0010-0277\(81\)90011-1](https://doi.org/10.1016/0010-0277(81)90011-1)
- Ornstein, P. A., Baker-Ward, L., Gordon, B. N., & Merritt, K. A. (1997). Children's Memory for Medical Experiences: Implications for Testimony. *Applied Cognitive Psychology*, 11(7), 87–104. [https://doi.org/10.1002/\(SICI\)1099-0720\(199712\)11:7<S87::AID-ACP556>3.0.CO;2-Z](https://doi.org/10.1002/(SICI)1099-0720(199712)11:7<S87::AID-ACP556>3.0.CO;2-Z)
- Poole, D. A., & White, L. T. (1993). Two years later: Effects of question repetition and retention interval

on the eyewitness testimony of children and adults. *Developmental Psychology*, 27(6), 975–986.

<https://doi.org/10.1037/0012-1649.27.6.975>

Richards, B. A., & Frankland, P. W. (2017). The Persistence and Transience of Memory. *Neuron*, 94(6),

1071–1084. <https://doi.org/10.1016/j.neuron.2017.04.037>

Rubin, D. C., & Schulkind, M. D. (1997). The distribution of autobiographical memories across the

lifespan. *Memory and Cognition*, 25(6), 859–866. <https://doi.org/10.3758/BF03211330>

Schacter, D. L., & Addis, D. R. (2007). The cognitive neuroscience of constructive memory: Remembering

the past and imagining the future. *Philosophical Transactions of the Royal Society B: Biological*

Sciences, 362(1481), 773–786. <https://doi.org/10.1098/rstb.2007.2087>

Sekeres, M. J., Bonasia, K., St-Laurent, M., Pishdadian, S., Winocur, G., Grady, C., & Moscovitch, M.

(2016). Recovering and preventing loss of detailed memory: differential rates of forgetting for detail types in episodic memory. *Learning & Memory*, 23(2), 72–82.

<https://doi.org/10.1101/lm.039057.115>

St. Jacques, P. L., & Schacter, D. L. (2013). Modifying memory: selectively enhancing and updating

personal memories for a museum tour by reactivating them. *Psychological Science*, 24(4), 537–543.

<https://doi.org/10.1177/0956797612457377>

Talarico, J. M., & Rubin, D. C. (2003). Confidence, not consistency, characterizes flashbulb memories.

Psychological Science, 14(5), 455–461.

Wixted, J. T., Mickes, L., & Fisher, R. P. (2018). Rethinking the Reliability of Eyewitness Memory.

Perspectives on Psychological Science, 13(3), 324–335.

<https://doi.org/10.1177/1745691617734878>

Wixted, J. T., Read, J. D., & Lindsay, D. S. (2016). The Effect of Retention Interval on the Eyewitness Identification Confidence–Accuracy Relationship. *Journal of Applied Research in Memory and Cognition*, 5(2), 192–203. <https://doi.org/10.1016/j.jarmac.2016.04.006>