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A novel study: hypermnesia for books read years ago

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ABSTRACT

Memory can increase across repeated tests without any further study, a finding known as hypermnesia (e.g., Erdelyi, M. H., & Kleinbard, J. (1978). Has Ebbinghaus decayed with time? The growth of recall (hypermnesia) over days. *Journal of Experimental Psychology: Human Learning and Memory*, *4*(4), 275–289). This study is the first to examine hypermnesia in a recognition test over long delays between learning and test. The current experiment examined hypermnesia for popular novels across retention spans of up to 10 years. Participants took two tests separated by 24 hours on a novel they had previously read. The tests had identical questions presented in a different order. We found hypermnesia across the recognition tests, which was due to within-test memory improvements. Hypermnesia decreased as a function of retention time due to increased item losses at longer delays. We propose a guessing hypothesis to account for this result and suggest that increased item losses are in part due to greater instability of memory at longer intervals.

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One of the most interesting findings in memory research is that memory performance can improve across repeated tests without feedback or additional learning opportunities (e.g., Erdelyi & Becker, 1974). This finding, known as *hypermnesia*, demonstrates that information can be temporarily forgotten, but not lost in memory, and that retrieval can serve to recover previously inaccessible information. In over a century of research on this phenomenon, very few studies have examined the occurrence of hypermnesia in complex information encountered outside of the laboratory. In addition, existing studies typically test for memory for very recently learned material, and often have the second memory test soon after the first (i.e., minutes or hours). Furthermore, hypermnesia is typically not assessed using a recognition test, as most studies use free or cued recall to assess memory (Erdelyi, 1996).

The current study examined the phenomenon of hypermnesia as part of our larger exploration of memory for events (Radvansky & Zacks, 2014) and is part of series of studies in our lab examining memory for novels (Copeland et al., 2009; Doolen & Radvansky, 2021; Radvansky et al., 2005). Specifically, we examined hypermnesia up to ten years after people had read one of four well-known fictional novels that are commonly read in American high schools: *Lord of the Flies*, by William Golding (1954), *To Kill a Mockingbird*, by Harper Lee (1999), *The Scarlet Letter*, by Nathaniel Hawthorne (1850/1999), and *1984*, by George Orwell (1949). The aim of the study is to better understand memory improvements for complex event information after testing years later. This was done by assessing recognition hypermnesia in memory for novels years after initial learning with a second test session occurring 24 hours after the first test. In addition, this study examined changes in hypermnesia magnitude for event information over ten years. This also allowed us to better understand the dynamics involved in hypermnesia and test several theories, including the elaboration hypothesis, the cue set change hypothesis, the retrieval difficulty hypothesis, and the retrieve-recognize model of hypermnesia.

The current study builds upon, and uses many of the methods, of a recent study that we did assessing recognition memory for novels (Doolen & Radvansky, 2021). That study assessed memory for events described in novels, with emphases on (a) the content and durability of memory, (b) causal connectivity among the described events, (c) serial position within the novel, (d) patterns of retention and forgetting, and (e) general interest in the novel. There were several primary findings from this study. First, we found that longer retention intervals led to poorer memory, but that the rate of forgetting was relatively shallow. Memory exhibited a primacy effect, but no recency effect (cf. Copeland et al., 2009; Radvansky et al., 2005). Also, causal connectivity of events within the context of the larger novel had a profound influence on

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memory, with more causally connected events being better remembered (cf. Radvansky et al., 2005; Trabasso & van den Broek, 1985). This was also found to be related to transition memory (Brown et al., 2016; Svob & Brown, 2012). Interestingly, transitional events showed evidence of linear forgetting, whereas poorly connected events were better fit by a power function. This drives home the importance of studying memory for complex events given that these are material characteristics that are absent in many traditional memory studies of things such as lists of largely unrelated items. There were some differences in patterns of forgetting for different event components, such as finding that temporal information was often poorly remembered. Finally, reported level of interest appeared to have little to no impact on our memory measures.

Hypermnesia overview

In a situation in which people receive two or more identical memory tests, some information that was retrieved on the first test may be forgotten on the second (*item losses*). This is the typical forgetting that we are most familiar with. In addition to this, some information that was not remembered on the first test can be recovered and reported on the second (*item gains*). The retrieval of information from memory that was inaccessible earlier, in the absence of relearning, is called *reminiscence* (Ballard, 1913). Overall, forgetting occurs when the proportion of item losses is greater than the proportion of item gains, resulting in a net decrease in memory. In comparison, hypermnesia occurs when the proportion of item losses is less than the proportion of item gains. This results in a net increase in memory between tests (e.g., Erdelyi & Becker, 1974; for a review, see Payne, 1987). Hypermnesia is related to the testing effect, which is the finding that memory performance is superior after retrieval practice compared to re-studying (e.g., Roediger & Karpicke, 2006).

Hypermnesia was first observed in experiments by Ballard (1913) when he tested memory for short prose passages in school aged children up to seven days after learning. Thus, research in this area began by exploring memory for relatively complex sets of information. Although interest in hypermnesia waned after inconsistent replication attempts (e.g., Buxton, 1943), interest renewed when hypermnesia was repeatedly and reliably found for images (Erdelyi et al., 1976, 1977; Erdelyi & Becker, 1974; Erdelyi & Kleinbard, 1978; Shapiro & Erdelyi, 1974). Since then, studies of hypermnesia have been reported using a variety of materials, including nonsense syllables (Roediger et al., 1982), words (Belmore, 1981), Socratic stimuli (Kazén & Solís-Macías, 2016), short prose passages (Otani & Griffith, 1998; Wheeler & Roediger, 1992), cartoons (Bergstein & Erdelyi, 2008; Erdelyi & Stein, 1981), films (Montangero et al., 2003), eyewitness memories (Dunning & Stern, 1992; Turtle & Yuille, 1994), and autobiographical memories (Bluck et al., 1999). That said, a notable aspect of all these studies is that the material being tested had been recently learned, and the delay between tests was often short, typically minutes or an hour.

Recognition hypermnesia

Hypermnesia has been reliably found in free recall and cued recall tests (Erdelyi, 1996), but has been difficult to obtain in recognition tests. One of the functions of the current study was to examine recognition hypermnesia by implementing a recognition test to assess memory. The dual process theory of recognition memory suggests that recognition involves two distinct processes: recollection and familiarity (Yonelinas, 1994). The retrieve-recognize model of hypermnesia (e.g., Bergstein & Erdelyi, 2008) suggests that hypermnesia can only be found on a recognition test when people actively recover qualitative information during the test (recollection) and then recognise that an item matches the test stimulus (familiarity). Bergstein and Erdelyi (2008) observed hypermnesia for cartoons (pictures with captions) in an old/new recognition test with the only image component of the cartoon presented (see also Erdelyi & Stein, 1981). The use of part-forms (i.e., the picture without the caption) during this test allowed for sufficient degradation of the memory to avoid ceiling performance. People could search memory for related information (the verbal caption) to identify a picture during the recognition test. Thus, to observe recognition hypermnesia, a recognition test must serve as a learning opportunity, there needs to be degradation of the initial memory trace to avoid ceiling level performance, and the initial memory needs to be recoverable through retrieval. When these conditions are not met, hypermnesia is not observed with recognition (e.g., Kazén & Solís-Macías, 1999; Otani & Hodge, 1991; Payne & Roediger, 1987).

In line with prior work, the recognition test in the current study serves as a learning opportunity because people must refer to memory for the events described in the novel to identify correct information on the multiple-choice recognition test, rather than relying on familiarity. In Experiment 1 of Doolen and Radvansky (2021), memory for these same novels was examined using the same recognition test (although only one test was given, not two) to explore several issues in memory unrelated to hypermnesia (e.g., forgetting patterns, serial position curves, causal connectivity). People remembered an average of 45% of information from the novels at an average of 3.7 years after learning (Range = .5–9 years). Thus, because the same procedure is used here, memory will not show ceiling effects. A follow-up analysis on the Experiment 1 memory data from Doolen and Radvansky (2021) randomly ordered recognition test showed that people remember 4% more on the final quarter of the test than the first, $t(212) = 4.21$, $p < .001$, even in the absence of feedback. This suggests that information is recoverable during retrieval, thereby improving performance on later test questions. According to the retrieve-recognize model (e.g., Bergstein & Erdelyi, 2008), the recognition test used in this study should be sensitive to hypermnesia.

The role of delay between study and test

To better understand the dynamics involved in recognition hypermnesia, we examine the influence of the retention interval between learning and test on hypermnesia. Existing work on the role of retention interval on hypermnesia has yielded conflicting findings. Wallner and Bäuml (2018) found that hypermnesia for images increased with retention interval on a free recall test but decreased with retention interval on a forced recall test. In partial agreement with this, Wheeler and Roediger (1992) found that hypermnesia decreased with retention interval on a forced recall test, but those time intervals were quite short. Still others found no changes of hypermnesia across the retention interval (e.g., Dunning & Stern, 1992; Roediger & Payne, 1982). Wallner and Bäuml (2018) suggest that the type of test plays a role in these disparate findings, making it necessary to examine recognition hypermnesia at varying retention intervals as well. No study has yet examined the role of retention interval on recognition hypermnesia. In addition, these studies used relatively short retention intervals, testing memory up to one week after learning. The current study will demonstrate the role of retention interval on recognition hypermnesia for complex materials on tests that occurred years after learning, and when 24 hours between the first and second memory test. Here, we review four theories to inform predictions for the role of retention interval between learning and test on recognition hypermnesia. The first two hypotheses predict that hypermnesia will decrease over time while the other two predict that it will increase. Note that the cumulative recall and retrieval strategy hypotheses are not considered for this study as they do not apply.[1]

Elaboration hypothesis

The *elaboration hypothesis* suggests that larger hypermnesia effects are observed for stimuli that promote elaborative processing, such as those that elicit greater levels of imagery (Erdelyi & Becker, 1974). This is also referred to as the *imagery hypothesis* because hypermnesia was found in memory for pictures, but not for words. Hypermnesia is also observed through other elaborative processes, such as when people form mental images, use a word in a sentence, or judge a word as being living or nonliving (Belmore, 1981). In essence, items that allow for elaboration are more likely to be recovered later, leading to hypermnesia. Evidence from autobiographical memory literature demonstrates that recent events are remembered more vividly than remote events (e.g., Cooper et al., 2019; Janssen et al., 2011). Thus, as levels of elaboration decline over time with increased forgetting, so should hypermnesia. Thus, the elaboration hypothesis predicts that the magnitude of observed hypermnesia will decrease over time since initial learning due to forgetting of memory components generated through elaboration and imagery. Specifically, this will result due to decreased item gains with longer retention intervals.

Retrieve-recognize model hypothesis

The retrieve-recognize model suggests that recollection, the active retrieval component to making a response on the recognition test, is essential to recognition hypermnesia. The dual process literature demonstrates that recollection declines over time (e.g., Gardiner, 1988; Gardiner & Java, 1991; Hockley & Consoli, 1999; Knowlton & Squire, 1995; for a review, see Yonelinas, 2002). Because recollection plays a more prominent role in memory tests taken after short delays compared to longer delays, hypermnesia should decrease as the retention interval between learning and test increases because of decreased item gains. Although research on recollection has focused on retention intervals six months and shorter, recollection was still above floor at six months, and so we assume that the pattern of declining recollection continues past six months until it reaches floor.

There is a connection between the elaboration theory and the retrieve-recognize model that needs considering. The elaboration hypothesis suggests that items that allow for elaboration are more likely to be recovered later, leading to hypermnesia. This can be explained by the retrieve-recognize model, which suggests that there needs to be degradation of the initial memory trace that is recoverable. Information that is elaborated upon has multiple components that make up the memory. The components are forgotten at different rates (Fisher & Radvansky, 2019), leaving a partial memory trace. This memory trace may not be sufficient to produce a memory on the first test. However, the forgotten components can be reconstructed and recovered using the remaining components in addition to new retrieval cues during testing, resulting in hypermnesia. In contrast, simple items, such as nonsense syllables or words that are less likely to be elaborated upon have fewer components to the memory trace, so when all the components are forgotten, it is harder to recover the memory, making it harder to observe hypermnesia. Thus, the retrieve-recognize model explains why elaboration is essential for hypermnesia.

Cue set change hypothesis

The *cue set change* hypothesis suggests that changes in the cues available at the time of retrieval results in the ability to retrieve previously inaccessible information (e.g., Raaijmakers & Shiffrin, 1980), resulting in item gains. There are greater contextual shifts over longer periods of time, resulting in a wider cue set and greater ability to retrieve previously inaccessible memories (Roediger & Thorpe, 1978). Thus, this view predicts that overall levels of hypermnesia will increase as time between learning and test increases because of increased item gains. However, this hypothesis has only been tested at relatively short retention intervals (Wallner & Bäuml, 2018). The current study will assess how contextual changes over very long retention intervals influences memory retrieval.

Retrieval difficulty hypothesis

Finally, the *retrieval difficulty hypothesis* (Hogan & Kintsch, 1971; Roediger & Karpicke, 2006) suggests that the initial retrieval of some memories strengthens them, making that information more accessible and reducing the forgetting of items (item losses), resulting in net hypermnesia. This is especially true when retrieval is more demanding. Because retrieval is more demanding after longer delays, this view predicts increased hypermnesia with longer delays because of reduced item losses. In line with this, the strongest memories tend to be retained at long periods of time and are more resistant to forgetting between tests. In comparison, at shorter intervals, both strong and weak memories are retained, and the weaker memories are less resistant to forgetting between tests.

Overall, each of these theories provides a different explanation for why hypermnesia occurs, and various predictions for what factors influence the observation of hypermnesia. The current study will shed light on the ability of these theories to capture hypermnesia for complex materials years after learning.

The current study

The current study is the first to examine recognition hypermnesia in very complex materials (novels) years after learning. In this study, participants took two online tests on their memory for a novel they had previously read years ago, outside of this study. The second test was given 24 hours after the first to allow for forgetting between tests. The two tests were identical, aside from the order of questions. The first aim of this study was to establish recognition hypermnesia for novels across memory tests taken years after learning. The second aim was to determine how recognition hypermnesia for these novels changes over time to better understand the dynamics of hypermnesia. To summarise the predictions for this, the elaboration and retrieve-recognize hypotheses both predict an overall decrease in hypermnesia over time; the cue set change hypothesis predicts an increase in item gains, resulting in net increases in hypermnesia over time; the retrieval difficulty hypothesis predicts a decrease in item losses, resulting in net increases in hypermnesia over time. We use novels to test the predictions for this study because doing so allows us to easily test memory for very complex materials over very long retention intervals, unlike what is possible with other types of materials. After presenting the study and results, we discuss our findings considering each of these theories.

Method

Participants

There were 290 undergraduates recruited from the University of Notre Dame who were provided partial credit towards their psychology course. Eighty-nine participants were ineligible to participate for reasons described in the procedure section. From the remaining 201, 59 people were removed from the analysis; 29 for not completing the second part of the study, 20 for completing the second part beyond 3 hours of the assigned time to do so, and 10 for reporting that they looked up information from the novel in between the two tests. The remaining 142 participants included in the analyses (108 female) were 18–23 years old ($M = 19.29$ years, $SE = 0.09$ years). From this sample, 48 participants answered questions about *Lord of the Flies*, 26 about *To Kill a Mockingbird*, 36 about *The Scarlet Letter,* and 32 about *1984*.

Materials

The materials from Doolen and Radvansky (2021) are used here. The following four books were selected from lists of books commonly read in American high schools: *Lord of the Flies*, by William Golding (1954), *To Kill a Mockingbird*, by Harper Lee (1960), *The Scarlet Letter*, by Nathaniel Hawthorne (1850/1999), *and 1984*, by George Orwell (1949). We divided each book into twelve sections. The event indexing model demonstrates that people represent different aspects of situations (i.e., person, object, …) in their event model (Zwaan et al., 1995; Zwaan & Radvansky, 1998). To achieve the aims of the earlier study (Doolen & Radvansky, 2021), for each section, we wrote multiple-choice questions to assess eight dimensions of participant's event memory (examples from *Lord of the Flies*, Chapter 4 in Appendix A). We assessed memory for *what* happened in the novel in addition to the *people* and *objects* in the events, and the *location* in which the events occurred. In addition, we tested memory for the time of the events, both *absolute time*, which is when things happened independent of other events (e.g., day of week, time of year) and *relative time*, which is when things happened in relation to other events in the story (e.g., before or after another event). Finally, there were questions regarding how events unfolded (*how),* and the causal explanation for the events (*why)*. There were an additional 20 questions for each book that were not specific to a particular event and were used to assess general memory for the novel. For example, the question "What age were the boys on the island?" assessed memory for *Lord of the Flies* which was not specific to a single part but was relevant to understanding the overall plot. Altogether, this resulted in 116 multiple choice questions for each novel. Each question was a four-alternative choice recognition item, with one alternative being correct in addition to three lures. All materials, data, and experiment code are publicly available through the Open Science Framework: https://osf.io/5hpws/.

Procedure

Phase 1

At the start of the study, participants provided demographic information and responded to questions relating to their internal and external environment during the study (i.e., What device are you using? Where are you? Who are you with? How noisy is your environment? How distracting is your environment? How awake/alert do you feel?). Participants then indicated which of the four novels that they had previously read: *Lord of the Flies*, by William Golding (1954), *To Kill a Mockingbird*, by Harper Lee (1960), *The Scarlet Letter*, by Nathaniel Hawthorne (1850/1999), and *1984*, by George Orwell (1949). Fourteen participants indicated that they had not read any of the four novels and were dismissed from the study at that point. The remaining participants were asked the following questions about their experience with the novels for which they indicated they had read:

1. "Please indicate which of the following books you ACTUALLY read all the way through. Check all that apply".
2. "Please indicate which of the following books you have NOT seen a film of. Check all that apply".
3. "Please indicate which of the following books you were NOT involved in a theatrical production of. Check all that apply".

These questions were asked to ensure that participants actually read the entire novel, and they did not learn about the novel from another source like a film or a theatrical production. Seventy-five participants were dismissed from the study for these reasons: 47 had not actually read any of the books all the way through, 7 had seen a film of any books they had actually read, and 2 had been involved in a theatrical production of any books they had actually read and not seen a movie of.

The remaining participants completed the study. Of the novels that they had actually read, not seen a film, and not been involved in a theatrical production, one was randomly selected for each participant. Participants then answered the 116 multiple-choice questions about that novel. Both the questions and the answer choices were presented in a random order. People responded by selecting the radio button next to their chosen answer and pressed the "Next" button on-screen when they were ready to advance to the next question. They were not able to return to previously answered questions. They had 30 seconds to answer each question to discourage the look-up of information during the assessment.[2] After participants finished the test, they were presented with a calendar reminder to complete the second part of the study.

Phase 2

Participants logged on to the experiment 24 hours after completing the first part. Participants responded to questions relating to their internal and external environment during the study participation and then indicated which book they answered questions about during the first part of the study. They then reported information related to their prior experience with reading the novel, including how many times they had read the selected novel, how long it had been since last reading it (providing an estimate in months and years), their level of enjoyment on a Likert scale from 1 (didn't enjoy at all) to 7 (enjoyed very much), and whether they had read that novel as an assignment or for pleasure.

Following this, people completed the test on the same novel as they had been tested on in Phase 1. The test procedure followed that outlined in Phase 1. The test questions were identical to those in the first test but presented in a different random order. At the end of this second test, participants were asked if they had looked up information about the novel between the first and second tests. They were also asked about their sleep (i.e., time went to sleep, time woke up, time spent falling asleep, minutes spent napping), alcohol and caffeine consumption, and activities participated in during the 24-hours inter-test interval.[3] At the end of the study, participants were debriefed about the purpose of the experiment and awarded credit.

Results

Descriptive information about learning

Because of the nature of this study, we had no control over participants' learning experience of the selected novel. Thus, any effects observed here will be robust to the range of participant's learning experiences. There were 134 people in this study reported having read the selected novel once, six had read the novel twice, and two had read the novel three times. In addition, 135 people reported that they originally read the selected novel as an assignment for school and the remaining seven had read the novel for pleasure. Moreover, on a seven-point Likert scale (1 "did not enjoy at all" to 7 "enjoyed very much"), people reported that, on average, they moderately enjoyed reading the novels ($M = 4.60$; $SE = 0.09$). As reported in Supplement A, memory was best for Lord of the Flies and To Kill a Mockingbird, and a separate analysis of the first memory test, unrelated to the current hypermnesia findings, is reported in Doolen and Radvansky (2021) as a replication of their study.

Hypermnesia

Overall memory performance per person was calculated as proportion correct, with chance performance being .25. Any questions skipped on either test were marked as

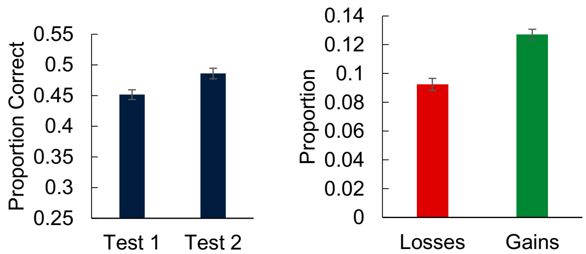

Figure 1. Hypermnesia = Gains > Losses.
Note: Error bars represent standard error.

wrong, with an average of 1.94 skipped on the first test (*SE* = .24) and 1.30 skipped on the second (*SE* = .24). People responded correctly to an average of .45 questions on the Test 1 (*SE* = .008) and .48 questions on the Test 2 (*SE* = .009). To determine if hypermnesia was experienced, Test 2 performance was compared to Test 1 (Figure 1). As expected, people remembered more of the information for Test 2 than Test 1, $t(141) = 7.74$, Mean Difference (M_d) = 0.03, $p < 0.001$, 95% Confidence Interval (*CI*) = (0.02, 0.04), Cohen's $d = 0.41$. As reported in Supplement A, the magnitude of hypermnesia was not significantly different among the four novels, $F(3,138) = 1.37$, $MSE = .002$, $p = .26$, $\eta^2 = .03$. In addition, we include an exploratory analysis of hypermnesia within each of the event dimensions in Supplement A for interested readers, but we did not have theoretical predictions for these.

This hypermnesia effect is the result of item gains on Test 2 ($M = 0.12$, $SE = 0.004$) being greater than item losses from Test 1 ($M = 0.09$, $SE = 0.004$), $t(141) = 7.77$, $M_d = 0.03$, $p < 0.001$, 95% $CI = (0.03,0.04)$, Cohen's $d = 0.80$. Thus, hypermnesia can occur for complex information even years after initial learning, and with a 24-hour inter-test interval.

Memory improvements within and between tests

As mentioned earlier, an analysis of Experiment 1 data in Doolen and Radvansky (2021) revealed memory improvement from the first to the final quarters of testing, which is identical to Test 1 here. Thus, it is possible that the hypermnesia observed here are due to improvement within the first test. To determine if there is a benefit of a second test, we compared memory both within and between tests. Each test was divided into quartiles, with each quartile containing 29 recognition questions. Note that the test questions were presented in a random order for each participant.

Focusing on the first and fourth quartiles, the results are presented in Figure 2. First, comparing memory for Test 1-Part 1 and Test 1-Part 4, there is significant improvement, $t(141) = 3.63$, $M_d = 0.04$, $p < 0.001$, 95% $CI = (0.02,0.07)$, Cohen's $d = 0.34$, with people correctly responding to .43 questions on average on Test 1-Part 1 ($SE = .01$) and .47 questions on average on Test 1-Part 4 ($SE = .01$). This is like what was found in the analysis of the Doolen and

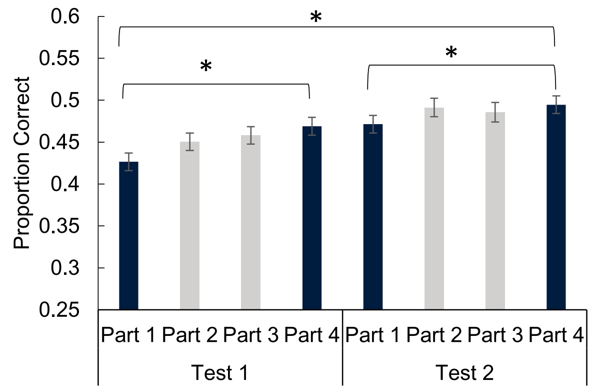

Figure 2. Memory within each quartile of both tests.
Note: * $p < 0.05$. Error bars represent standard error.

Radvansky (2021) data. We next compared memory for Test 1-Part 4 and Test 2-Part 1 to examine between-test changes. Memory at the start of Test 2 did not differ from that at the end of Test 1, $t(141) = 0.24$, $M_d = 0.002$, $p = 0.81$, 95% $CI = (-0.02,0.02)$, Cohen's $d = 0.02$, with people correctly responding to .47 questions on average on Test 2-Part 1 ($SE = .01$). Thus, the overall memory improvements perseverated but did not grow across the 24-hour inter-test delay. After this, we compared memory for Test 2-Part 1 to Test 2-Part 4 and found that it improved, $t(141) = 2.27$, $M_d = 0.02$, $p = 0.03$, 95% $CI = (0.003,0.04)$, Cohen's $d = 0.18$, with people correctly responding to .49 questions on average on Test 2-Part 1 ($SE = .01$). This contributes to the overall hypermnesia effect. There is an additional benefit of the second test to memory for these novels. Finally, we compared memory for Test1-Part 1 to Test 2-Part 4 to examine the overall improvement. Memory at the end of Test 2 was better than memory at the start of Test 1, $t(141) = 6.22$, $M_d = 0.07$, $p < 0.001$, 95% $CI = (0.05,0.09)$, Cohen's $d = 0.55$. Notice that this improvement ($M_d = 0.07$) is much larger than the overall comparison of Tests 1 and Test 2 ($M_d = 0.03$). Thus, the actual magnitude of hypermnesia due to testing is larger than we observed.

Hypermnesia over time

People reported having read the target novel 0.8–10 ($M = 4.18$; $SE = 0.10$) years prior to testing. To determine whether the magnitude of hypermnesia changes over time, the Test 2 – Test 1 difference was plotted against time since the reported last reading. These values are shown in Figure 3. This change over time was modelled using linear regression. Here, time significantly predicted the magnitude of the hypermnesia, $r^2 = 0.03$, $MSE = 3.01$, $F(1,141) = 4.75$, $p = 0.03$, $B = -5.99$, $C = 4.39$, with the magnitude decreasing with longer retention intervals. Thus, benefits from one test to another were more likely to occur when the original reading was more recent, and memory traces were more likely to be stronger.

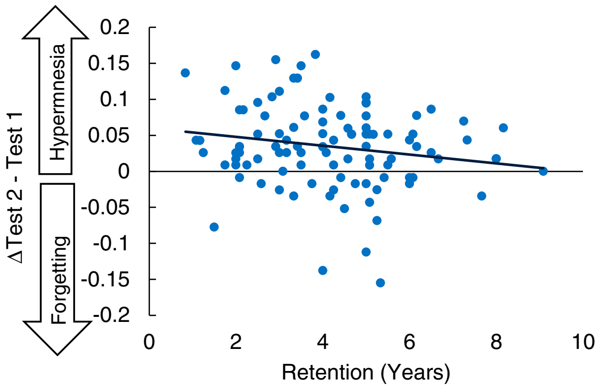

Figure 3. Memory improvement over time.

Next, item gains and losses were regressed against time to better understand why hypermnesia decreased with longer retention intervals (Figure 4). The proportion gains (reminiscence) did not change over time, $r^2 < 0.001$, $MSE = 3.12$, $F(1,141) < 1$. However, item losses (forgetting) significantly increased, $r^2 = 0.04$, $MSE = 2.98$, $F(1,141) = 6.40$, $p = 0.01$, $B = 7.38$, $C = 3.51$. Thus, the hypermnesia over time is the result of increased between-test losses paired with stable reminiscence.

General discussion

Recognition hypermnesia

The results of the present study support prior findings of hypermnesia in recognition tests (e.g., Bergstein & Erdelyi, 2008). This is very interesting because recognition hypermnesia has been previously difficult to obtain. The retrieve-recognize model suggests that recognition hypermnesia can only be observed when ceiling level performance is avoided, the initial memory needs to be recoverable through retrieval, and there is a retrieval search during the recognition test. The current materials satisfy these three criteria. The materials used in this study were naturalistic and lent themselves to elaboration. Because the present study avoided ceiling effects, memory was sufficiently degraded to allow for recovery of forgotten information. Furthermore, because people had to distinguish between the correct answer and three other choices that were familiar and plausible, people likely used recollection in addition to familiarity to respond. Thus, although we do not provide a direct test of the model, our present results are in line with the retrieve-recognize model. Further work implementing a remember/know/new procedure to assess the role of recollection during the test may prove to be a fruitful avenue to determine if the retrieve-recognize model fully accounts for present findings of recognition hypermnesia.

Memory improvements within and between tests

We found that memory improved within both the first and second tests. Within-test improvements are in line with the cue set change hypothesis. People create very rich and elaborate mental models when reading novels. As people take the recognition test, the probes provide new cues and people can reconstruct memory for the novel. Retrieval of one aspect of an event model can activate related concepts. Thus, more cues are available at the end of the test than at the beginning, resulting in improved performance. We observe this pattern on both tests.

Interestingly, although memory continued to improve throughout the second test, there was no memory improvement between the end of the first test and the beginning of the second. Thus, hypermnesia was not a result of the addition of a second test, but instead due to within-test processes. This finding is seemingly consistent with the retrieval time hypothesis, as presented by Roediger and Thorpe (1978). They found that, on a free recall test, people who took three 7-minute short tests separated by 1-minute breaks performed no different than those who took one 21-minute test, equivalent in total duration. They conclude that hypermnesia is a result of allowing participants more recall time, rather than a result of multiple tests. An important difference between

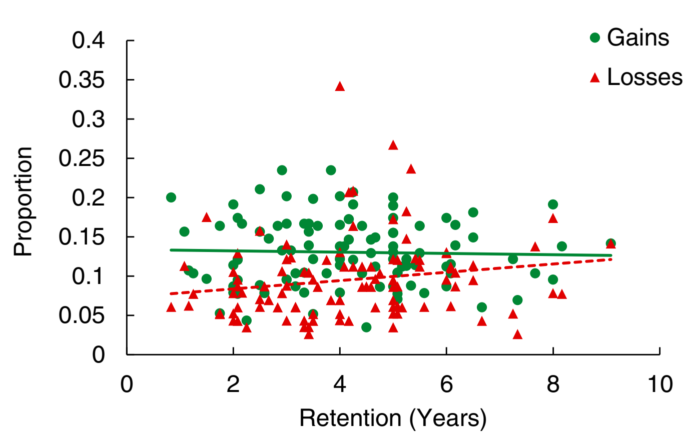

Figure 4. Memory for gains and losses over time.

these two studies, though, is the extended inter-test interval in the present study (24 hours) compared to the 1-minute inter-test interval in Roediger and Thorpe (1978). However, the current study had no direct test of the retrieval time hypothesis (e.g., having people spend 20 seconds vs 40 seconds answering each question) to conclude this. In the current study design, it is impossible to tease apart the role of retrieval time and the increased availability of new cues throughout the test. Even if the results can be attributed to retrieval time, at least in part, it is unlikely that time itself is producing increased memory. Instead, it is the processes active during the extended time, notably the ability to use alternative retrieval pathways to access the information, that result in improved memory. Thus, we conclude that the availability of new cues and use of alternate retrieval pathways is the driving force behind our results.

Furthermore, we suspect that overall performance in the current study would have been greater (more closely resembling memory at the end of Test 2) if people had an opportunity to go back and change answers when they completed the first test. Such a finding would be instructive for student's test taking strategies (i.e., more reason to go back and check your answers before submitting your test – the change of 7% observed here is nearly a whole letter grade difference).

Hypermnesia decreases over time

Across a retention interval spanning 10 years, we observed a decrease in net hypermnesia. It is difficult to compare the present results with prior work that examined hypermnesia on recall tests up to one week after learning. Wallner and Bäuml (2018) found increased hypermnesia across free recall tests for words and pictures across various delays (3 minutes versus 1 day; 11.5 minutes versus 1 week). However, they also found that hypermnesia decreased for forced recall test of pictures between 11.5 minutes and 1 week. Similarly, Wheeler and Roediger (1992) only found hypermnesia on immediate forced recall tests for pictures, but not for tests taken after one week, suggesting decreasing hypermnesia over time with forced recall. Thus, different processes are involved in producing hypermnesia in free and forced recall. The results of the current study most closely resemble the findings with forced recall. In line with Wallner and Bäuml (2018), we examine item gains and losses over time to better understand our results.

Item gains stable over time

Two theories (the elaboration hypothesis and retrieve-recognize model) predicted that item gains would decrease over the retention interval, and one theory (the cue set hypothesis) predicted that item gains would increase. We did not observe this. Instead, gains remained stable over time. This is consistent with all four of Wallner and Bäuml's (2018) experiments.

Regarding the elaboration hypothesis and retrieve-recognize model, there are likely other processes involved that overshadow the predicted results. As we discussed in the introduction, it is possible that the recoverable memory gap increased over time. If that is the case, then it is still possible that the proportion of item gains proportional to the recoverable memory gap did decrease, but we do not have enough evidence to conclude this.

Regarding the cue set hypothesis, greater contextual shifts at longer intervals were predicted to result in more alternate retrieval pathways used to access previously inaccessible memories, thereby increasing gains. There are several explanations for why this was not observed here. First, the amount of context change reaches an asymptote at longer retention intervals, resulting in diminished returns. The amount of contextual change from 24 hours to 1 week later is much larger than the amount of change from 1 to 10 years after learning. This may be why we do not see an increase in hypermnesia over time here. In addition, the context change may not be relevant to producing new cues relevant to the to-be-remembered material. In our analysis of within- and between-test improvements, we found that memory improved within tests but not between-tests. We interpret this as support for the cue set change hypothesis in that memory improved when there were cues relevant to the novel. Thus, our finding of stable item gains over time do not rule out the operation of cue set change influences in other circumstances.

Greater losses over time

The retrieval difficulty hypothesis predicted that losses would decrease over the retention interval as retrieval becomes more demanding. However, we found the opposite – increased losses over time. In some ways, this contradicts Wallner and Bäuml (2018) results. They found reduced item losses for free recall, but no changes for forced recall. Recognition is not as difficult as recall because people can rely on familiarity in addition to recollection to make a response. Because of this, item retrieval during the first test may not increment the strength of retrieved items enough for those items to be retrieved again on the second test, particularly for items with weaker strength after longer retention intervals. This can help explain why losses increased with longer retention intervals in this study. Thus, this finding can be interpreted as consistent with the retrieval difficulty hypothesis.

However, this still leaves our finding of increased losses over time somewhat unexplained. We propose a *guessing hypothesis*. The basic premise of this hypothesis is that memories become more unstable over time, resulting in more guessing on tests taken after longer delays, and more losses between tests. The few previous studies of hypermnesia across multiple delays have only examined recall, and so did not need to account for guessing.

We test this hypothesis by looking at how often people changed their answers between tests. To do this, we

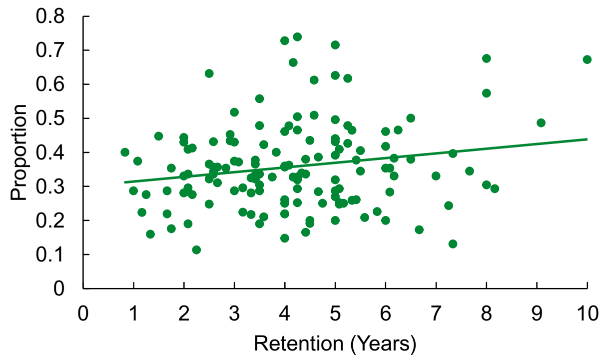

Figure 5. Proportion of answer changes as a function of time.

summed up the number of times people switched an answer from the first to second test, including item losses, item gains, and changes from one incorrect answer to another. As can be seen in Figure 5, memory was more unstable at longer retention intervals, $r^2 = 0.04$, $MSE = 3$, $F(1,141) = 5.31$, $p = 0.02$. Unfortunately, we do not have enough information to determine what responses were made based on true memory as compared to guessing. Because this hypothesis is speculative, more work is needed, perhaps collecting confidence ratings during the recognition test. Furthermore, Otani and Whiteman (1994) found that hypermnesia resulting from cued recall of words was not different from forced cued recall, where people were instructed to guess if they did not know. One way to examine the role of guessing is to create a recognition test for which participants can skip questions they do not know. A finding of no differences in hypermnesia on a recognition test with and without guessing would argue against this guessing hypothesis.

The asymptotic retrieval principle

Although we did not use the cumulative recall hypothesis to form predictions due to extended inter-test interval and use of recognition in the current study, we can consider a proposition from this theory, which we refer to as the Asymptotic Retrieval Principle. This principle suggests that greater hypermnesia is found in materials that are remembered better initially. For example, Roediger et al. (1982) tested this hypothesis by manipulating the degree of learning, with a list of nonsense syllables presented to participants either one or three times before three recall tests. People who saw the items three times had greater hypermnesia compared to those who only saw the items once. The idea here is that better learned materials have a higher asymptotic level of recall whereas lesser learned materials have a lower asymptote. A lower asymptotic level of recall is quicker to reach, and the first test is more likely to exhaust the pool of recoverable information.

Wallner and Bäuml (2018) had previously hypothesised, based on this principle, that hypermnesia would decrease over extended retention intervals because of decreased item gains as the asymptotic level of retrieval is lowered with time. However, this hypothesis does not consider the gap between initial memory and the asymptote, which we refer to as the *recoverable memory gap*. If the asymptote declines slower than initial memory, the recoverable memory gap will grow larger over the retention interval (greater potential for item gains over time). If the asymptote declines faster than initial memory, the recoverable memory gap will grow smaller (less potential for item gains over time). If they decline at the same rate, then the recoverable memory gap will stay the same (stable potential for item gains over time).

Unfortunately, asymptotic performance exists in theory, and we can only hypothesise about asymptotic performance if we have participants take many tests on the material until their memory reaches an asymptote. Furthermore, this principle does not consider the underlying mechanisms that result in item gains when there is a recoverable memory gap. Other explanations, such as reconstruction of memory traces activating alternate retrieval pathways to recover the memory, are needed to explain the cause of item gains. With this said, we conclude that there does need to be a recoverable memory gap (which is one of the requirements in the retrieve-recognize model) to obtain hypermnesia, but this principle should not be used to make predictions regarding when hypermnesia will or will not be observed in the current study.

Conclusion

This study was the first to examine recognition hypermnesia with naturalistic materials over very long retention periods. We found that recognition memory can improve across tests taken years after learning, providing support for the idea that hypermnesia can indeed be found with recognition. This hypermnesia was seemed to be a result of within-test improvement only because there was no improvement between tests. Recognition hypermnesia decreased over time because of increased item losses paired with stable item gains. Because no study has tested recognition memory over delays before, existing theories were insufficient to explain the increase in item losses. We propose a guessing hypothesis – the idea that memory is less stable at longer delays, resulting in more guesses, increased item losses, and net decreases in the magnitude of the hypermnesia over time. Furthermore, through reconciling our results with existing theories, we consider how seemingly competing theories can fit together as dynamic pieces of the hypermnesia puzzle.

Notes

1. The *cumulative recall hypothesis* suggests that the magnitude of hypermnesia is related to the cumulative level of recall across multiple tests, and that hypermnesia is a result of longer retrieval time (Roediger et al., 1982). As such, this hypothesis applies to tests that are close in time, within minutes of one another. Because of this, the cumulative

retrieval hypothesis is not be applicable for our study, in which tests are separated by 24 hours. Furthermore, this hypothesis applies to studies which implement recall to test memory. We do provide a consideration of the asymptotic retrieval principle that focuses exclusively on retrieval levels. The *retrieval strategy hypothesis* suggests that each retrieval attempt improves the strategies used to organize retrieval, resulting in more efficient recall on subsequent tests and fewer item losses between tests (e.g., Mulligan, 2001). Because this hypothesis is applicable for free recall, but not recognition, this hypothesis is not considered further here.

2. Average response time was 7.5 seconds ($SE = .21$ seconds). One person had unusually low response times, but their inclusion did not influence the pattern of results, so we elected to keep them in the analysis.
3. This information was collected for thoroughness should it be of interest for future research, but responses to these questions are not examined here because it is not of interest for our current research question.

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Appendix

Table A1. Example of questions assessing the eight dimensions of event memory for Lord of the Flies.

Dimension	Question from *Lord of the Flies*, Chapter 4
What	What did Jack do with the first pig they killed? 1. He roasted the pig 2. He gave it as a sacrifice to the beast 3. He used it to scare the little'uns 4. He ate the pig's flesh raw
People	Who destroyed the little'uns' castles? 1. Roger 2. Simon 3. Piggy 4. Ralph
Objects	After Jack painted his face, what did Piggy want the boys to help him make? 1. A sundial 2. A fort 3. A bow and arrow 4. A signal fire
Location	Where did Jack paint his face? 1. Next to the fire 2. The end of the river 3. In the lagoon 4. On the mountain
Absolute Time	When did Piggy's specs get broken? 1. When Jack smacked Piggy's head 2. When he tripped over a rock 3. When they were re-lighting the signal fire 4. When the boys are fighting for food
Relative Time	When did Simon point out there was no longer smoke rising? 1. After Jack painted his face 2. Before the boys started building huts 3. Before Jack went hunting 4. After Jack left the group
How	How did Roger behave toward Henry? 1. He threw stones at him 2. He growled at him 3. He behaved friendly around him 4. He acted shy around him
Why	Why did Jack smear mud over his face? 1. So the pigs wouldn't see him 2. To scare the little'uns 3. To attack Ralph 4. To protect his skin from sunburn

Note. The first answer choice is correct as presented here.