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Permalink

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Journal

Proceedings of the National Academy of Sciences of the United States of America, 110(52)

ISSN

0027-8424

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Publication Date

2013-12-24

DOI

10.1073/pnas.1314373110

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False memories in highly superior autobiographical memory individuals

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Edited by George Sperling, University of California, Irvine, CA, and approved October 22, 2013 (received for review July 29, 2013)

The recent identification of highly superior autobiographical memory (HSAM) raised the possibility that there may be individuals who are immune to memory distortions. We measured HSAM participants' and age- and sex-matched controls' susceptibility to false memories using several research paradigms. HSAM participants and controls were both susceptible to false recognition of nonpresented critical lure words in an associative word-list task. In a misinformation task, HSAM participants showed higher overall false memory compared with that of controls for details in a photographic slideshow. HSAM participants were equally as likely as controls to mistakenly report they had seen nonexistent footage of a plane crash. Finding false memories in a superior-memory group suggests that malleable reconstructive mechanisms may be fundamental to episodic remembering. Paradoxically, HSAM individuals may retrieve abundant and accurate autobiographical memories using fallible reconstructive processes.

hyperthymesia | DRM | suggestion | crashing memories

Research on memory distortion suggests that episodic memory often involves a flawed reconstructive process (1–3). Several false-memory paradigms developed in recent decades have demonstrated this. For example, in the Deese-Roediger and McDermott (DRM) (4, 5) paradigm, people falsely remember words not actually presented in a related list of words. In the misinformation paradigm, the content of a person's memory can be changed after they are exposed to misleading postevent information (2, 6, 7). In the nonexistent news-footage paradigm (also known as the "crashing memory" paradigm), people sometimes recall witnessing footage of news events for which no footage actually exists (8, 9). People can even remember events following an imagination exercise that inflates their certainty about events that they only imagined but did not actually experience (10). Even memory for our past emotions seems to be reconstructed and prone to error (11). So far, memory distortions have been investigated in subjects who have typical memory ability [children (12), adults (7), older adults (13)], but not with people with unusually strong memory ability. Memory-distortion phenomena have been explained by theoretical models that state that memory is reconstructed from traces at retrieval (1, 3, 14), is not reproduced from a permanent recording (15), and is prone to errors caused by source confusion (16) and association (17, 18). These studies and theoretical models paint a picture of human memory as malleable and prone to errors.

However, a small number of individuals who have recently been identified appear to be uniquely gifted in their ability to accurately remember even trivial details from their distant past (19–21). Highly superior autobiographical memory (HSAM; also known as hyperthymesia) individuals can remember the day of the week a date fell on and details of what happened that day from every day of their life since mid-childhood. For details that can be verified, HSAM individuals are correct 97% of the time (20). For example, when one individual was asked what happened on October 19, 1987, she immediately responded with, "It was a Monday. That was the day of the big stock market crash and the cellist Jacqueline du Pré died that day." HSAM individuals can remember what happened on a day a decade ago better than most people can remember a day a month ago. In some ways, these abilities seem to be at odds with what we know about the reconstructive, unreliable, and malleable processes underlying memory in people with typical memory.

HSAM abilities are distinct from previously described superior-memory individuals (22–25) who typically rely upon practiced mnemonics to remember unusually long lists of domain-specific data, yet remain average in their ability to retrieve autobiographical information. In contrast, HSAM individuals seem not to be superior learners, exhibiting average scores on typical laboratory memory tasks that are unrelated to autobiographical memory. Furthermore, HSAM individuals recall their past in rich detail and in a fashion that seems automatic and unaided by explicit mnemonic techniques or rote practice. It is puzzling that not all HSAM individuals report keeping diaries, routinely refreshing information (e.g., "what did I do on this day last year?"), or categorizing and cataloging their experiences on certain dates in their minds. The sheer amount of the personal experiences that they can recall fluidly seems highly unusual, and on objective measures of autobiographical memory the statistics are astounding. For example, on the very challenging 10 Date Quiz (see below), the mean score for HSAM participants is 25.5 SDs above the mean score for control participants (Cohen's d). Structural MRI brain scans of people with HSAM have shown morphological differences in areas, such as the temporal gyri, that have been previously described as contributing to autobiographical memory (20). These areas were different in size and shape

Significance

In a unique memory-distortion study with people with extraordinary memory ability, individuals with highly superior autobiographical memory (HSAM) were as susceptible as controls to false memory. The findings suggest that HSAM individuals reconstruct their memories using associative grouping, as demonstrated by a word-list task, and by incorporating postevent information, as shown in misinformation tasks. The findings also suggest that the reconstructive memory mechanisms that produce memory distortions are basic and widespread in humans, and it may be unlikely that anyone is immune. The assumption that no one is immune from false memories has important implications in the legal and clinical psychology fields, where contamination of memory has had particularly important consequences in the past.

Author contributions: L.P., S.J.F., A.K.R.L., N.P., R.M.N., C.E.L.S., J.L.M., and E.F.L. designed research; L.P. and A.K.R.L. performed research; L.P., S.J.F., N.P., and R.M.N. analyzed data; and L.P., S.J.F., A.K.R.L., N.P., R.M.N., C.E.L.S., J.L.M., and E.F.L. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

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This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1314373110/-/DCSupplemental.

compared with age- and sex-matched controls, but conclusions have yet to be made as to if these differences are a result of nature, nurture, or both.

Here, we tested HSAM individuals' susceptibility to memory distortion in the DRM, misinformation, nonexistent news footage, imagination inflation, and memory for emotion paradigms (see *SI Materials and Methods* and Figs. 1–3 for materials and procedural details). We recruited 20 HSAM participants and 38 age- and sex-matched controls. Seven of these 20 HSAM participants had previously been identified as HSAM individuals in prior published studies (19, 20) and 13 are new to the literature. HSAM participants were identified using a 30-question Public Events Quiz (PEQ) and a 10 Date Quiz (20). These tests are exceedingly difficult for control participants with normal memory. The PEQ consisted of 15 questions that asked participants to give the date of a well-known public event, and 15 questions that gave them a date and asked them to report a significant public event. The 10 Date Quiz consisted of 10 randomly generated dates for which participants were to give the day of the week that they fell on, a verifiable event within a month's time of them, and a description of a personal autobiographical event that occurred on each of the dates. HSAM participants showed unusually high scores on both measures, compared with controls (*SI Materials and Methods*).

Are people with HSAM abilities vulnerable to the same kinds of distortions and errors that others are, or do their abilities protect them in some way from suggestive influences? The answer to this question will help elucidate both the workings of HSAM and the nature of human memory more generally. If each memory-distortion paradigm produces false memory in a group with superior memory (as well as average-memory individuals, as shown in past research), perhaps the malleable reconstructive memory system is a fundamental part of human episodic memory. If we find HSAM individuals are only susceptible to some distortions, but not the semiautobiographical ones (nonexistent news footage, imagination, and memory for emotion), it suggests they retrieve memories in the autobiographical domain differently than the rest of the population. If HSAM participants show no memory distortions in any paradigm, such evidence would question the view that malleable, reconstructive, and fallible memory is in fact characteristic of all groups of people.

Results

To investigate the relationship between HSAM ability and memory distortion susceptibility, we first compared HSAM individuals to age- and sex-matched controls on a range of memory-distortion tasks. We then performed a median split on HSAM participants, comparing the 10 who scored above the HSAM median on the PEQ (one of the objective measures of autobiographical memory ability), to the 10 who scored below that median (for a median split analysis on the 10 Dates Quiz, see Fig. S1).

Fig. 1 shows the DRM word-list false-memory task. There was no significant difference between false-memory rates (recognition of critical lures: words not presented earlier, but related to presented words) of HSAM individuals (M = 70.3%, SD = 17.1%) and controls [M = 70.8%, SD = 19.9%; $t(55) = -0.10$, $P = 0.922$] (Fig. 1*B*). HSAM participants and controls incorrectly indicated they had seen an average of 14 of the 20 critical lures (HSAM range 8–20). In addition, there was no reliable difference in false-memory rate for HSAM individuals scoring low and high in the PEQ measure of autobiographical memory ability (Fig. 1*D*) [$t(17) = 0.86$, $P = 0.403$]. There were also no significant

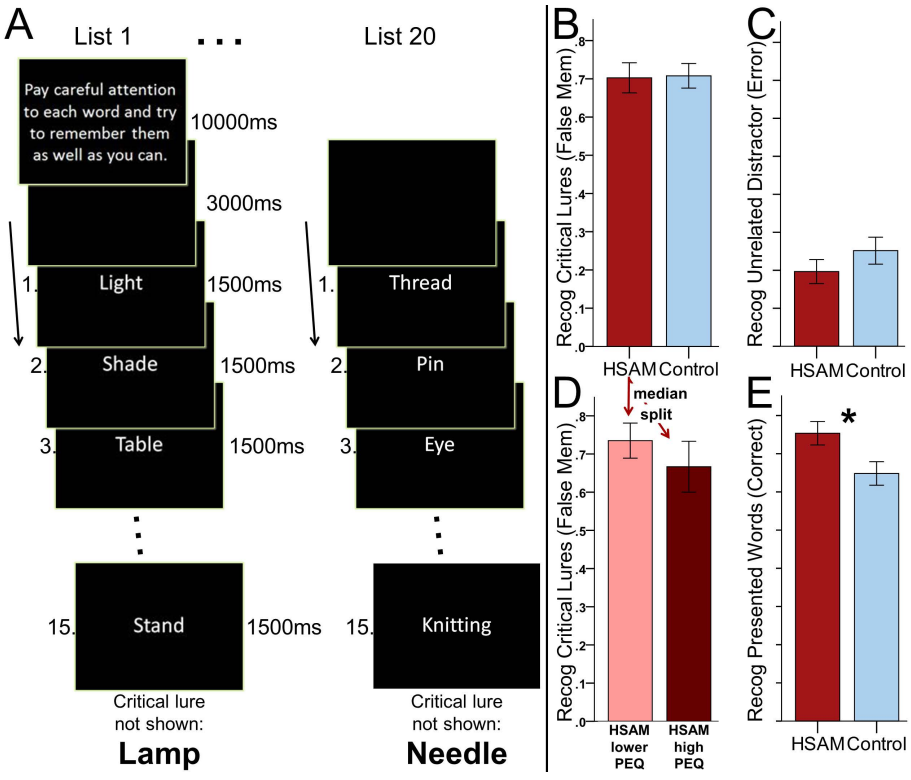

Fig. 1. The DRM false-memory associative word list: a sample of materials and the main results. (*A*) The materials consisted of 20 lists, each 15 words long. Each word in a given list is related to a critical lure that the participants never actually saw. (*B*) The main result showed both HSAM individuals and controls falsely recognized a similarly high proportion of critical lures ($M_{HSAM} = 14.1$; $M_{Control} = 14.2$ of 20). The *y* axis indicates the mean proportion. (*C*) Both groups indicated seeing unrelated distractor words at the same proportion as one another, far less often than they endorsed seeing the critical lure words. (*D*) HSAM participants with the highest autobiographical memory ability (highest scores on the PEQ) were not significantly less susceptible to falsely endorsing critical lure words than HSAM participants who performed in the low range. (*E*) HSAM individuals outperformed controls on correctly recognized items that were presented earlier (hit rate), $*P = 0.035$. Error bars represent SEs.

differences in error rates of recognizing unrelated distractor words that were neither presented earlier nor related to presented words (Fig. 1*C*) (HSAM participants 19.7%, controls 25.2%, $P = 0.323$; percentages in keeping with past DRM research). However, we found that HSAM individuals correctly recognized significantly more presented words (M = 76.6%, SD = 14.2%) than controls [M = 64.8%, SD = 19.0%), $t(55) = 2.16$, $P = 0.035$]. A signal detection analysis revealed HSAM participants were better at discriminating presented words from critical lures than controls, but no better at discriminating unrelated distractors from presented words (Fig. S2).

We next compared HSAM individuals to controls on their false-recognition rates of the five most emotionally arousing critical lure words, and on the five least arousing critical lures. This analysis revealed no significant differences between HSAM participants and controls [emotional: $t(55) = -0.39$, $P = 0.699$; neutral: $t(55) = 0.17$, $P = 0.870$].

On the misinformation task (Fig. 2), a statistically significant misinformation effect was observed in both groups. Exposure to misinformation caused participants to incorporate that information into their memory for the original stimulus at significantly higher rates than those who were not exposed (Fig. S3).

We quantified the misinformation false memories by two metrics. Consistent with prior research (26), overall false memories (OFM) consisted of trials in which the participant chose the misinformation version during the memory test (e.g., pants pocket) (Fig. 2*C*). Source-confirmed false memories (SCFM) consisted of trials in which the participant further confirmed during the source test that he or she explicitly remembered seeing the image in the original photographic slideshow (Fig. 2*D*). Contrary to being immune from false memories on this test (Fig. 2*E*), HSAM participants (M = 2.65, SD = 1.53) had significantly more OFM than controls [M = 1.92, SD = 1.10, $t(56) = 2.09$, $P = 0.041$]. There was no reliable difference in the OFM score between those HSAM individuals with the highest autobiographical ability (PEQ) and the other HSAM participants (Fig. 2*G*) [marginal P value: $t(18) = -1.74$, $P = 0.098$]. Similarly, HSAM participants and controls showed remarkably similar SCFM scores (Fig. 2*F*) [$t(56) = 0.19$, $P = 0.848$] and there was no reliable evidence for a difference between the two sets of HSAM participants (Fig. 2*H*) [$t(18) = -1.47$, $P = 0.160$].

Taken together, these results indicate that the HSAM group exhibited false memories in the misinformation paradigm. The HSAM individuals with the best autobiographical memory were just as susceptible, if not more, to developing false memories, compared with HSAM participants with lower scores on the PEQ.

Next, in the nonexistent news-footage paradigm, we examined the tendency of HSAM participants and controls to report having seen the nonexistent plane crash footage in the computer questionnaire (Fig. 3 and *SI Materials and Methods*). Fig. 3*D*

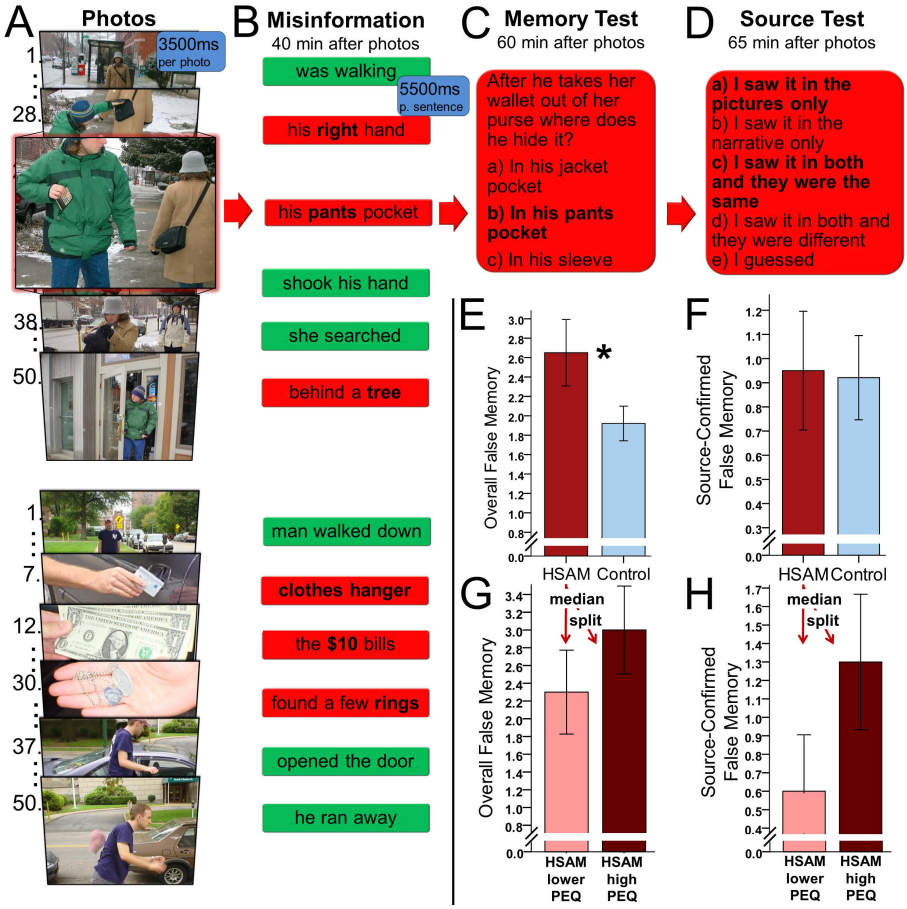

Fig. 2. The misinformation paradigm. (*A*) Participants saw two events that unfolded in slideshows consisting of 50 photographs each. The first event featured a man stealing a wallet from a woman while pretending to help, and the second event showed a man breaking into a car with a credit card and stealing $1 bills and necklaces. (*B*) Later, participants read two narratives consisting of 50 sentences each, with six items of misinformation surreptitiously placed in among the 94 true sentences. (*C*) In the memory test, picking the misinformation consistent response is counted as an OFM. (*D*) In the source test, if one also indicates it was seen in the photos it is counted as a SCFM. The *y* axis gives the mean number of false memories. (*E*) HSAM participants had significantly higher OFM than controls and (*F*) about the same SCFM. There were no statistically significant differences on either OFM (*G*) or SCFM (*H*) between those HSAM individuals who scored highest on the PEQ and HSAM participants who had lower PEQ scores. Time intervals between *A*, *B*, *C*, and *D* are approximate. Error bars represent SEs.

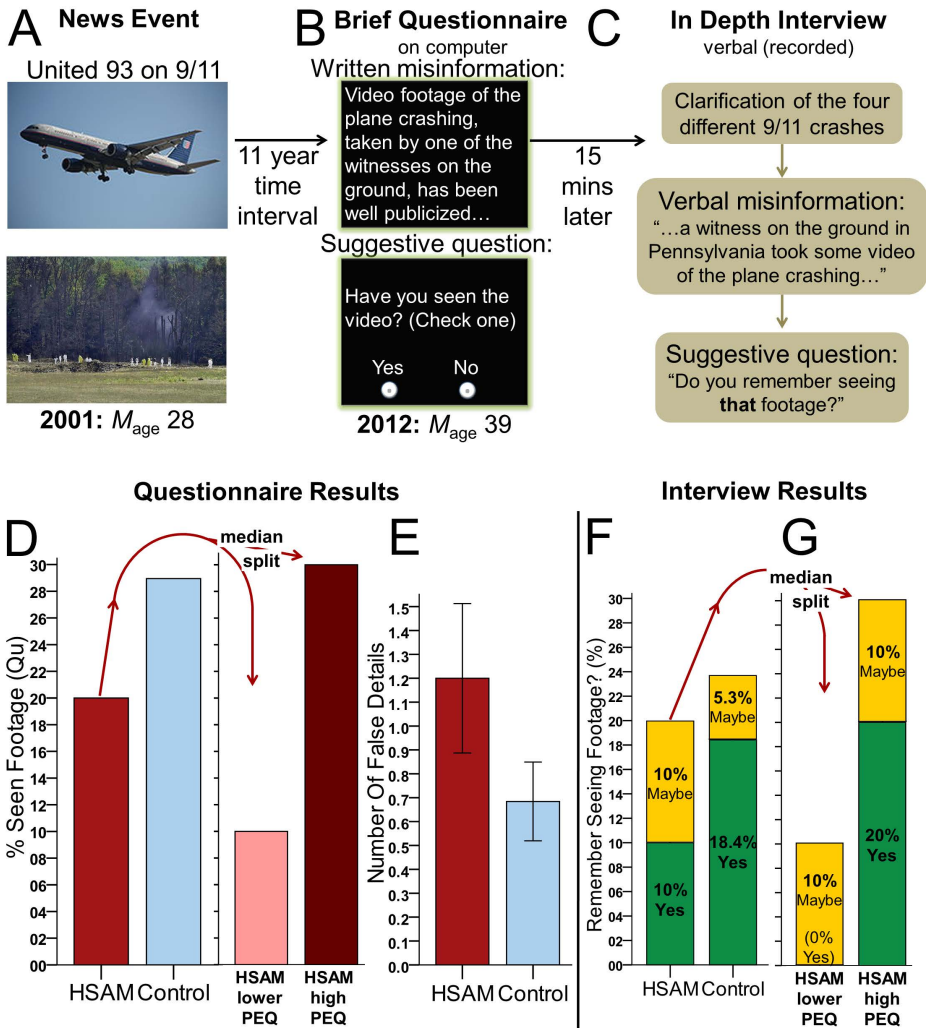

Fig. 3. Materials and results of the nonexistent news-footage paradigm. (*A*) The target news event is the crash of United 93 in Pennsylvania. (*B*) The computer questionnaire stated that footage of the actual crash exists and asked participants to check whether they have seen the footage. (*C*) Later an in-depth interview carefully explained what we were asking about, and asked them if they had seen that footage. (*D*) In the computer questionnaire, 20% of HSAM individuals and 29% of controls indicated they had seen the footage. A median split of HSAM participants on the PEQ revealed 30% with higher PEQ scores indicated "yes" they had seen the footage; only 10% with lower PEQ scores did so. (*E*) The number of false details (of a possible four) indicated HSAM individuals were not statistically significantly higher than controls ($P = 0.11$). (*F*) In the interview, 10% of HSAM participants and 18% of the controls said yes they had seen the footage, and (*G*) a median split revealed that the highest-scoring HSAM individuals on the PEQ were no less susceptible than those HSAM participants lower on the PEQ. Error bars represent SEs.

shows that 20% of HSAM individuals reported that they had seen the footage and a similar 29% of controls reported that they had seen it (Fisher's exact test, $P = 0.541$). There were also no differences in the number of false details remembered from the footage (Fig. 3*E*) between HSAM participants (M = 1.20, SD = 1.40) and controls [M = 0.68, SD = 1.02; $t(56) = 1.61$, $P = 0.113$]. These results, when combined, suggest comparable susceptibility to false memories in the nonexistent news-footage paradigm.

The nonexistent news-footage interview provides a more conservative measure of false memory than the computer questionnaire. Even in these interviews, we found both the HSAM group (Fig. 3*F*) as a whole and the most-capable HSAM individuals (Fig. 3*G*) had nonzero susceptibility to semiautobiographical false memories. Using a 2 (HSAM, control) × 3 ("yes," "maybe," "no") Fisher's exact test, we found no evidence for a difference in susceptibility (Fig. 3*F*) ($P = 0.608$). Comparing high PEQ HSAM to lower PEQ HSAM participants (Fig. 3*G*) yielded a similar nonsignificant result (Fisher's exact test $P = 0.721$). Excerpts from transcripts of a HSAM and control participants demonstrating these false memories are available in *Sample Nonexistent News-Footage Interview Transcript Excerpts*.

Finally, we also found susceptibility to memory distortions in the imagination inflation and emotion memory consistency paradigms in both HSAM individuals and controls (Figs. S4 and S5), with no evidence for enhanced resistance to distortion in the HSAM group. Table S1 summarizes both the autobiographical memory scores and memory distortion measures for each HSAM in the analysis, and suggests that no participant was immune to memory distortion. In addition, we found no consistent relationship between age and susceptibility to memory distortion.

Discussion

Prior HSAM research showed a remarkable ability in these individuals to recall even distant autobiographical information with an exceptional level of accuracy. This finding might imply that this population would be one of the most likely groups to be immune to memory distortions. However, we found that HSAM participants were as comparably susceptible to memory distortions as controls. This result was true on both relatively neutral word lists and more emotionally involved tasks. HSAM individuals showed normal levels of susceptibility to misremembering nonexistent news footage when misleading suggestion or imagination exercises were given. Significant news

events, such as the crash of flight United 93 on September 11, 2001, are semiautobiographical in nature. These are events that HSAM participants usually recall with far greater accuracy and detail than controls, at least in the absence of misinformation and other distorting influences. Given that we had reason to expect HSAM individuals to be one of the least likely groups in the population to be vulnerable to memory distortions, this set of results, combined with previous research, gives credence to the hypothesis that potentially fallible memory reconstruction mechanisms are ubiquitous and a part of normal human memory. In most situations the reconstructive processes involved in memory are accurate. However, situations that make them inaccurate in the typical population will also make them inaccurate in this special population.

HSAM participants had significantly more OFM in the misinformation task than controls. This result indicates that HSAM participants, like others, are using memory reconstruction at the time of recall and that they are vulnerable to confusing one source (photos) from another (text narratives). To better understand this result, we compared HSAM individuals to controls on individual difference measures that could indicate a strong tendency to attend to and visualize the misinformation narratives. Indeed, we found that on the measures of absorption (Tellegen Absorption Scale) and fantasy proneness (Creative Experiences Questionnaire) HSAM participants were significantly higher than controls. The absorption measure captures "openness to absorbing and self-altering experiences" (27), and the fantasy-proneness measure involves the tendency to have vivid childhood memories and fantasize in a way that feels real (28). Controlling for these measures in a multiple regression eliminated the statistically significant difference between HSAM individuals and controls on OFM (Table S2). This analysis implies that absorption accounts for at least some of the reason that HSAM participants had more OFM, and that could be because of a deeper involvement or visualization during the misinformation narratives.

Because HSAM individuals outperform controls on autobiographical memory tasks, and because emotion is thought to play a role in the encoding of such events, it was quite possible that HSAM participants would be less susceptible to distortion of emotional information than controls. However, we found no evidence of this on the DRM test when we compared the most emotionally arousing critical lures to the most neutral words. Nor did we find conclusive evidence of this on the nonexistent news footage or imagination inflation task involving a news report of a potentially emotion-laden nationally significant plane crash. We did find that HSAM individuals were more consistent than controls in remembering some types of emotions, but were as inconsistent as controls on others (Fig. S5).

Another way to view HSAM individuals is as experts in the domain of their own autobiographical past. There is some evidence that experts are more likely to experience false memory for domain-relevant material using DRM word lists (29). Although in the present study we did not find higher false memories in HSAM individuals' own domain of expertise, our conclusion that HSAM individuals use reconstructive retrieval processes to access their domain of expertise is compatible with that previous research.

HSAM individuals are a newly discovered, scientifically interesting group. The present results build on previous HSAM research that identified their unusually high autobiographical ability (19–21). On daily life details from their personal past, HSAM individuals have abundant and accurate recall (20). Our findings do not contradict this. In fact, in the nonexistent news-footage interviews we found examples of HSAM individuals' rich and very detailed autobiographical memory that were congruent with past research (*Example of a HSAM Individual's Response that Demonstrated Detailed Autobiographical Memory Ability*). We also know that their exceptional ability does not extend to traditional, nonautobiographical, and neutral laboratory tests of memory with relatively short study–test intervals (20). Similar results were observed in the current study as we observed similar performance to controls when photographs were used in recognition memory testing. We should note that HSAM participants were slightly more accurate at recognizing presented words in the DRM task. Their advantage here is not of the magnitude observed for autobiographical memory. The present study adds the knowledge that HSAM individuals as a group are comparably susceptible to a number of memory-distortion phenomena. Extraordinary autobiographical memory accuracy does not necessarily imply false-memory immunity. Despite their apparent accuracy of an extremely large memory store, HSAM individuals seem to be using the same reconstructive memory mechanisms that people with typical memory use.

It seems paradoxical that the HSAM group showed vulnerability to memory distortion yet remember an abundant amount of autobiographical information accurately for years. Their abundant accuracy could be the end result of strong autobiographical memory traces combined with little or no misinformation. If reminders of their personal past, such as diaries, photos, videos, conversations with family, news stories, and so forth, contain little misinformation then there may be very little distortion in their recall. In addition, it also seems puzzling why HSAM individuals remember some trivial details, such as what they had for lunch 10 y ago, but not others, such as words on a word list or photographs in a slideshow. The answer to this may be that they may extract some personally relevant meaning from only some trivial details and weave them into the narrative for a given day.

There is a question as to whether the participants were confidently reporting genuine memory distortions or merely guessing or making mistakes. Although we cannot be completely sure that a participant really experienced a visual false memory, we did ask questions that were designed to try to ascertain whether actual distortion was occurring. For example, in the DRM word-list procedure, the vast difference in endorsement of critical lures (about 70%) compared with unrelated distractors (about 20%) tells us that a good proportion of the critical lure endorsements are false reports/memories, rather than guesses. In the misinformation procedure, we found significantly higher misinformation endorsement in the experimental group compared with the control group, which means that at least some of the memory errors are not merely guesses or mistakes. We also had a source test in which many participants confirmed they had seen a misinformation detail in the original photographs, indicating relatively high confidence of a false memory. In the nonexistent news-footage procedure, the in-depth and detailed interview revealed that some participants had high confidence in their false memory because they gave false details, or by a high score on the final question: "How well do you remember seeing the video, from 1 = no memory at all, to 10 = very clear memory?" Of those who said they had seen the video, 56% gave a score on this scale above 5, suggesting that many were confident of their false memory (see also transcripts in *Sample Nonexistent News-Footage Interview Transcript Excerpts*).

A small sample size may typically pose limitations, but in this case it did not because we found typical levels of memory distortions in HSAM participants and controls. In all cases the rates were reliably above zero and in several cases the HSAM participants were showing at least trends toward higher levels of false memories. In addition, one could argue that the nonexistent news-footage target event was only semiautobiographical in nature, and not a fully personal memory. This aspect is both a strength and a weakness: on the one hand 9/11 was a public event that we know most people experienced and we know for sure the footage does not exist, but on the other hand it may not

have been as personally significant as are other autobiographical events (e.g., weddings).

HSAM individuals possess a remarkable autobiographical memory. However, these results show that even they are not immune to episodic memory distortions. Whatever the source of their exceptional autobiographical memory ability is, this does not prevent them from having memory distortions. Although it is always possible that some group might be found to be immune to memory distortions, none has as yet been discovered.

Materials and Methods

Over two sessions, 1 wk apart, 20 HSAM and 38 age- and gender-matched controls participated in a number of memory distortion tasks. Twenty DRM associative word lists were presented, followed by test. Misinformation paradigm materials were presented in the form of photographical slideshows, text narratives with some misleading items, and memory and source tests. Nonexistent news footage was suggested both in computer questionnaires and in verbal interviews.

ACKNOWLEDGMENTS. Many thanks to Larry Cahill and Elizabeth S. Parker for their previous research on highly superior autobiographical memory; Nancy Collett; and all the research assistants, including Fellows of University of California at Irvine's Undergraduate Research Opportunity Program. This research was supported by National Science Foundation Graduate Research Fellowship Program (L.P.), Sigma-Xi Grant-in-Aid (to L.P.), the Gerard Family Trust (J.L.M.), Unither Neurosciences (J.L.M.), Public Health Service National Institute of Mental Health MH12526 (to J.L.M.), and National Institutes of Health Grant 1R01AG034613 (to C.E.L.S.).

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Supporting Information

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SI Materials and Methods

Highly Superior Autobiographical Memory. Hundreds of people claiming to have highly superior autobiographical memory (HSAM) contacted the J.L.M. laboratory after national news reports [e.g., *60 Minutes* (1)] of the phenomena. Of these participants, 172 claiming to have HSAM were screened. These participants were identified as HSAM individuals or not, based on our two objective measures of autobiographical memory, the Public Events Quiz (PEQ) and the 10 Dates Quiz (10DQ). The PEQ consisted of 30 questions. The test contained two types of questions: 15 asked for the exact date of a given significant public event that took place within the individual's lifetime; for example, "When did an Iraqi journalist hurl two shoes at President Bush?" The other 15 questions asked for the significant public event that took place on a given date that took place within the individual's lifetime (e.g., what public event occurred on October 11, 2002?). In addition, for all 30 questions, individuals were asked to state the day of the week the date fell on. The significant public events given were selected from five different categories so as to increase the chances that the participant had experienced it. Those categories were sporting events, political events, notable negative events concerning famous people, and holidays. The participant received one point for each correctly identified category (i.e., the event, the day of the week, the month, the date, and the year) and could achieve a total of 88 possible points. A very strict score of 50% or above qualified an individual claiming to have HSAM to advance to the second even more challenging round of screening, the 10 Dates Quiz. Control participants with average memory who did not claim to be HSAM individuals scored an average of 12.63%, 35% maximum. This conservative measure ensured that the HSAM pool contained only those participants who were proficient at accurately recalling event-related information that they had experienced in their lifetime.

The 10DQ consisted of 10 computer-generated random dates, ranging from the individual's age of 15 to the day of testing. Individuals were asked to provide three different categories of information for each of the 10 dates generated: (*i*) the day of the week; (*ii*) a description of a verifiable event (i.e., any event that could be confirmed via a search engine) that occurred within plus or minus 1 mo of the generated date; and (*iii*) a description of a personal autobiographical event the individual participated in on that date. One point was awarded for the correct day of the week, for giving a verifiable event confirmed as true, and for giving a personal autobiographical event. A maximum of three points per date could be achieved (30 points total). A score of 65% or above, representing the average of all three categories, qualified the individual as an HSAM participant. Controls averaged 11.12% on this quiz. This very conservative measure was taken so as to ensure that an HSAM participant was proficient at accurately identifying events, whether in the public or private domain, and the days of the week they occurred.

As a result of testing many participants who thought they might have HSAM, 30 had passed the criteria for HSAM at the time of recruitment (2012) and of these we were able to recruit 21 for the present study. One participant was excluded from this particular article's analysis because of visual impairment, leaving 20 HSAM participants. We recruited 38 age- and sex-matched controls from the general public that were within 4 y in age to their corresponding matched HSAM. Each HSAM had at least one, usually two age- and sex-matched controls. As a result, the mean age in each group was almost identical (HSAM M_{age} = 38.6 y, SD = 10.8, range 21–62 y; controls M_{age} = 39.0 y, SD = 10.5, range 21–60 y; $P = 0.9$).

Memory Distortion. ***Materials background literature.*** We used several well-established paradigms to assess memory distortion in the HSAM population. For example, in the Deese-Roediger and McDermott (DRM) (2, 3) paradigm, participants are shown a list of words that are all related to a word that was not presented, called the critical lure. For example, typically 10 or 15 words are presented, such as "rest," "bed," "nap," "peace," and the critical lure word "sleep" is not shown. In the subsequent memory test, typically a few minutes later, "sleep" is falsely remembered by a remarkably high proportion of participants (recall: 61%; recognition: 80%) (4). This high proportion is much higher than the recognition rates for words that were not presented nor related to presented words (unrelated distractors; recognition rates typically around 20%). This task suggests that memory works in an associative way, whereby one object or event activates a web of objects or events that are related, and that the activation of a related item (5) can be incorporated later as a memory for that item when memory is reconstructed at retrieval.

Another approach for examining false memories is called the "misinformation" paradigm. A typical misinformation paradigm involves a three-phase process. Participants initially view an event stimulus (usually photographs or a video) and are later presented with some misleading information about the event. When subsequently tested, they are asked to report their memories of the original stimulus (6). Often, participants incorporate the misinformation presented at the second phase into their memories of the original event. This result is typically taken as evidence that the source of some acquired information can be confused with the original event, called a source-monitoring error (7), and that memories are reconstructed.

In the nonexistent news-footage (aka "crashing memory") paradigm, participants are falsely told that there is news-footage for a well-known news event. As the name suggests, the event chosen by researchers has often been a crash (8), but has also involved news stories about other types of upsetting events, such as bombings and assassinations (9). Participants are asked whether they remember the footage in a way that strongly implies that such footage exists. A surprisingly high proportion of participants typically report having seen the nonexistent footage (e.g., 55%) (8) and many report details (e.g., 45%) (8), indicating that participants formed a memory rather than just a belief they had seen the nonexistent footage. This paradigm produces one of the closest parallels to real-life traumatic memories that are otherwise either impossible to study because of ethics concerns or difficult to interpret because of uncertainty as to whether the reported event actually occurred. These studies show us that elaborate false memories can be created for upsetting events by postevent information, such as news stories of important disasters, and are not just confined to word lists or misinformation laboratory studies.

Other research on imagination inflation (10) has shown that guided imagery and suggestion can be used either to increase confidence that an unlikely event happened in a participant's personal past or to plant memories of entire events that did not happen. Sometimes these events are mildly upsetting in an attempt to mimic real-life situations, where suggestions are made that something traumatic happened. Moreover, even memory for our past emotions has been shown to be vulnerable to change, tending to shift toward our current appraisal of the original

events (11). All of these research paradigms suggest fallible and malleable reconstruction during memory retrieval.

Memory distortion materials and procedure. In the memory-distortion part of the study, subjects were paid $40 each for ∼3 h of participation. Subjects participated at their home on their own computer, with the researcher connected to them via Skype video-chat or phone for the entirety of both sessions 1 and 2. We required participants to have the computer on a desk and themselves be sitting on a chair. Researchers advised the participants before the study commenced on how to avoid distractions and interruptions. We excluded one participant from this article's analysis because of visual impairment. We excluded one further participant from only the DRM analysis, who indicated they remembered seeing every single word on the test, indicating noncompliance with that part of the study.

To disguise the fact that we were investigating false memories, we gained Internal Review Board approval (University of California at Irvine Institutional Review Board; HS#2011–8038) to tell participants the study was about personality, individuality, and slideshows. The instructions they read briefly mentioned that their memory would also be tested in the study, but the instructions did not mention memory distortion or false memory. This aspect was necessary because subjects' awareness of the topic of the study, memory distortion, can bias their memory reports.

We used well-established validated DRM word-list materials (4), in which we presented 20 15-word lists (the study phase) and a few minutes later tested their recognition (Fig. 1). The lists used in this study had the following critical lures: Lamp, Trash, Slow, Wish, Foot, Window, Soft, Chair, River, Stove, Anger, Justice, City, Rough, Mountain, Music, Thief, Doctor, Cold, and Needle. In our analysis comparing the more emotionally arousing critical lures to more neutral critical lures, we used arousal scores of those critical lures from the Affective Norms for English Words (12).

We incorporated the misinformation paradigm using previously established, reliable materials (13) involving a slideshow of two photographic stories involving nonviolent crimes (Fig. 2*A*), narratives that described the stories but contained six instances of misleading information (Fig. 2*B*), and a recognition memory test (Fig. 2*C*) followed by a source-of-memory test (Fig. 2*D*). If a participant indicated they saw the misinformation-consistent response in the recognition memory test (Fig. 2*C*), they were identified as having an overall false memory (OFS). If they also indicated in the source test (Fig. 2*D*) they had seen that in the photographs, that is called a source-confirmed false memory (SCFM).

In our nonexistent news-footage procedure, the United 93 plane crash in Pennsylvania on September 11, 2001 was used as the target news event, for which we suggested there was footage of the actual crash when in fact there is no such footage (Fig. 3*A*–*C*). We used wording that had worked well in earlier testing in our laboratory, and participants completed both a computer-based suggestive questionnaire about their memory of the nonexistent news footage and an audio-recorded structured interview about 15 min later. In the interviews, the researcher clarified which event we were asking about, then repeated the suggestion about the video of the crash, and then asked the participant if they had seen the footage and whether they remembered any details contained in the footage.

We also took two other measures of memory distortion/inconsistency. One measure was a brief imagination inflation exercise in the interview whereby participants who had not initially said they had seen the footage were taken through a few minutes of imagining what the footage "might have looked like." Any increase in certainty of seeing this footage after the inflation exercise represented some effect of imagination on memory. We also asked participants to report how often they experienced several negative emotions in the week following the 9/11 attacks. They reported this twice, once in session 1 a week before any memory distortion tests were done, and again in session 2 immediately after the questions about United 93's crash on 9/11. This process provided a measure of their consistency of their memory of emotions from one week to the next.

All nonexistent news-footage interview recordings were independently coded by two research assistants. Coders categorized answers to "yes/no" type questions into three categories: "yes" (coded 1), "maybe/unsure" (coded 0.5), and "no" (coded 0). Interrater reliability was high for the first question asking if they had seen "that footage," Cronbach's $\alpha = 0.938$. Cronbach's α for the similar question asked after the imagination inflation exercise was 0.887. When a discrepancy between two codings arose a senior researcher listened to the recording and resolved the discrepancy to the most accurate coding.

Sample Nonexistent News-Footage Interview Transcript Excerpts.

Excerpts from a HSAM participant's interview showing false memory.

Interviewer: As you might recall, on September 11, 2001, two planes were flown into the World Trade Center in New York City, one plane was flow into the Pentagon in Washington, DC, and another plane, United 93 crashed in a field in rural Pennsylvania. The plane crash in Pennsylvania is the event we are interested in asking you about. The other crashes on 9/11 have already been studied, so we focusing only on United 93, the one that crashed in a field in Pennsylvania. Are you familiar with this event?

HSAM (subject no. 2): Oh yes.

Interviewer: Can you tell me what you remember about the event?

HSAM: Um, What I can remember from the event that I went home. Uh, I went home that afternoon, uh, saw it on the news. Basically, what I remember is that there was a field that had, a plane that had crashed in a field that day. The stories alleged that it was headed to the White House although nobody really knew for sure. Uh, it was later determined that uh, the passengers uh, overpowered the hijackers, and caused it to uh, caused it to, uh, to end up in Pennsylvania. I think it was something like, I am not sure about this, but I think it was a flight out of Cleveland that was headed for, I don't remember. And I'm not, I think it was headed out of Cleveland but I can't say with certainty. Uh, and a couple of days later I saw the footage of the video.

Interviewer: Okay well, as you mentioned and as you might know, a witness on the ground in Pennsylvania took some video of the plane crashing and it has been widely shown on TV news and the internet in the months and years since the attack. Do you remember seeing that footage?

HSAM: Yes, but a couple of days later.

Interviewer: OK, Can you tell me what you remember about the footage?

HSAM: Uh, I saw it going down. I didn't see all of it. I saw, uh a lot of it going down uh, on air.

Interviewer: Ok, do you remember how long the video is?

HSAM: Just a few seconds. It wasn't long. It just seemed like something was falling out of the sky. It was probably was really fast, but I was just, you know, kind of stunned by watching it you know, go down.

Interviewer: Ok, so now is the last question, I would like for you tell me how well you can remember having seen the video on the scale from 1 to 10, where 1 means no memory at all and 10 means a very clear memory?

HSAM: I'd say about 7.

Excerpts from a control participant's (without HSAM) interview showing false memory. **Interviewer:** As you might recall, on September 11, 2001, two planes were flown into the World Trade Center in New York City, one plane was flow into the Pentagon in Washington,

DC, and another plane, United 93 crashed in a field in rural Pennsylvania. The plane crash in Pennsylvania is the event we are interested in asking you about. The other crashes on 9/11 have already been studied, so we focusing only on United 93, the one that crashed in a field in Pennsylvania. Are you familiar with this event?

Non-HSAM (subject no. 130168): Yes, a little bit.

Interviewer: Can you tell me what you remember about the event?

Non-HSAM: I don't remember so much of that one because a lot of the attention was on the two planes that hit the buildings, but I did hear that another landed somewhere else, and I think there was some kind of uprising—something happened during it and we don't exactly where it was headed but where it landed wasn't the intended destination, and that is about as familiar I am with it.

Interviewer: As you might know, a witness on the ground in Pennsylvania took some video of the plane crashing and it has been widely shown on TV news and the internet in the months and years since the attack. Do you remember seeing that footage?

Non-HSAM: Very vaguely, I think it was kind of blurry the noise was kind of sharp in some places. It wasn't high resolution by any means but the resolution was okay considering its time. I don't remember the specific details of the video—how long it was or what was in the context of it, but I vaguely remember seeing it.

Interviewer: Can you describe how the plane moved in the footage?

Non-HSAM: I think what I am remembering is that it was a little rocky but I don't think the camera was very steady but it didn't look very stable as it was moving across the screen.

Interviewer: Do you remember how the plane crashed in the video?

Non-HSAM: I don't think it was a hard crash, but it wasn't a soft one by any means I think there was definitely impact and definitely injuries I think, or if I had been there I imagine I would have been injured, so definitely looked impromptu and not planned at all.

Interviewer: Ok, now, I would like for you tell me how well you can remember having seen the video on the scale from 1 to 10 where 1 means no memory at all and 10 means a very clear memory?. . .

Non-HSAM: . . .I would say about a 7.

Example of a HSAM Individual's Response that Demonstrated Detailed Autobiographical Memory Ability. Note: Personal (not news-related) names were changed in this excerpt Minor redactions were made to protect anonymity. "Um"s and "uh"s were removed for ease of read.

Interviewer: Can you tell me what you remember about the event?

HSAM (subject no. 4): Sure, what I remember about Shanksville. . . Pennsylvania was that I heard about it of course after the other three attacks, and it was almost like an aftermath event because September 10th, excuse me, September 11th was a very patriotic day and I remember that Tuesday of course, everything you saw on the news was about the World Trade Center.

In fact just to backtrack a bit to explain what I remember about Shanksville, is that I remember seeing of course the World Trade Center on TV, I had had to. I usually had my Tuesday morning yoga class, I would study in the library before yoga, and then right before yoga I would come to eat lunch in my dorm room because I didn't have time for cafeteria lunch, and so as my roommate Lisa is getting ready and as we're watching the TV, we hadn't turned on the TV all day and so we finally turned it on and we're trying to see the Maury show, because it usually came on in the morning in New York, and all we saw was just purple smoke in New York City, and Tom Brokaw speaking, and so we thought okay, a special report, maybe there's a plane crash or something in the area, and then she turns to go to the mirror to do her hair, she was blow drying her hair, and I'm sitting on this, this chair eating my Easy Mac macaroni and cheese and, that's when they showed the recap of the second tower falling and I remember screaming like it was a horror movie because someone just blew up the World Trade Center. And so, again it was a lot of chaos, and shortly afterward we found out that classes were canceled. We were a Catholic women's school so there was a memorial service in the chapel, people trying to find out if their loved ones were okay. I had my aunt and uncle working in lower Manhattan, and you know, trying to find out if they made it home okay, which they eventually did.

My best friend Sara, she, I remember hugging her and crying and we stayed in her dorm room the whole time pretty much after mass. And I remember one of the memories also about that day, and again trying to relate this to Shanksville is that, we had an emergency meeting in the dorms, and again a very black day, but Sara and I always joke about it because of the way the [job title redacted] handled himself. The [job title redacted] was trying to get this meeting together of all of the women to explain what was going on, and it was a very hot day, and he assembled us all on the porch of the dorm, and it's like 80 something degrees in Westchester County New York, and so all he was saying, all I remember him saying was "I am [Name Redacted] I am [Name Redacted], there are no planes flying today I am [Name Redacted]." And that was the whole extent of his meeting, and that's why me and Sara just made fun of the fact that he's really ineffective in being a leader in emergencies.

And so, as things are coming together, as I'm watching the news, because the whole day pretty much just stayed in her dorm room, and I think we just went out to dinner at the cafeteria. And that was about it, just stayed in her room the whole day watching the TV and in the aftermath that's when we heard about Shanksville. To my memory, and you know I didn't see any video of the plane going down in Shanksville, not like I saw with the recaps of the World Trade Center, or even with the burst of fire that you saw from the distance of the Pentagon. I just remember seeing footage of the plane being down. I remember like it looked like a crumpled up ball of metal, like you could see the nose, I think you could see wings, some windows, and just a little bit of smoke. It was kind of like a greyish picture in this field in Shanksville. And that's all I remember about it, and they were later connecting it, or figured out that this was the fourth plane.

I remember very much, of course, the story about Todd Beamer and how he supposedly said "Let's roll." I remember very much the fact that his wife was pregnant. I think they found out that they were having a boy, and that boy should be about 10 years old today, so definitely I remember the Todd Beamer story and thinking how sad it was for his, not so much for his, I didn't think about the baby losing the father but my sympathies most with the wife that here's your husband who's supposed to be your best friend and he's died and you're left to raise this child alone. So that was what really stood out to me.

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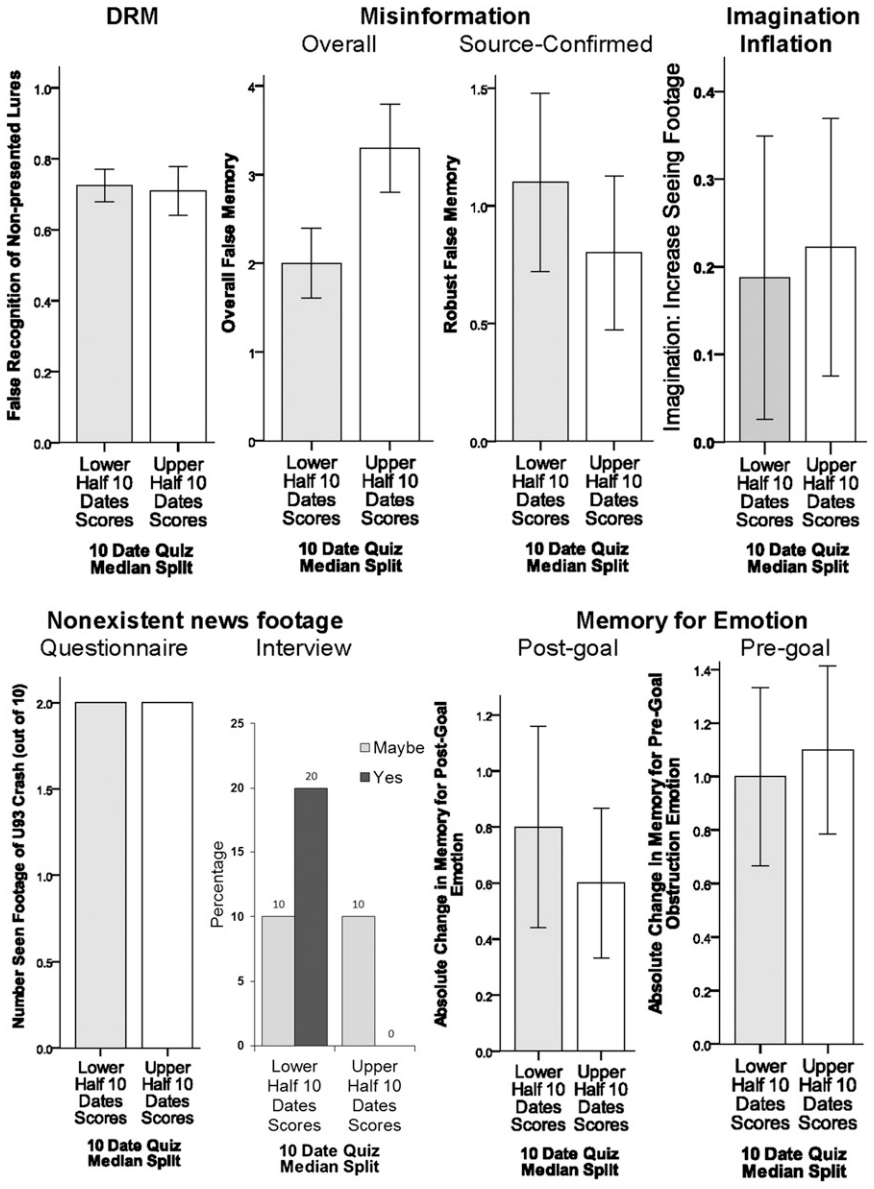

Fig. S1. A median split of HSAM participants by their 10DQ score: A comparison of memory distortion measures. HSAM individuals in the upper half of the 10DQ had significantly more OFM than HSAM participants lower on the 10DQ, $t(18) = -2.38$, $P = 0.029$. All other comparisons shown were not statistically significant. Error bars represent SEs.

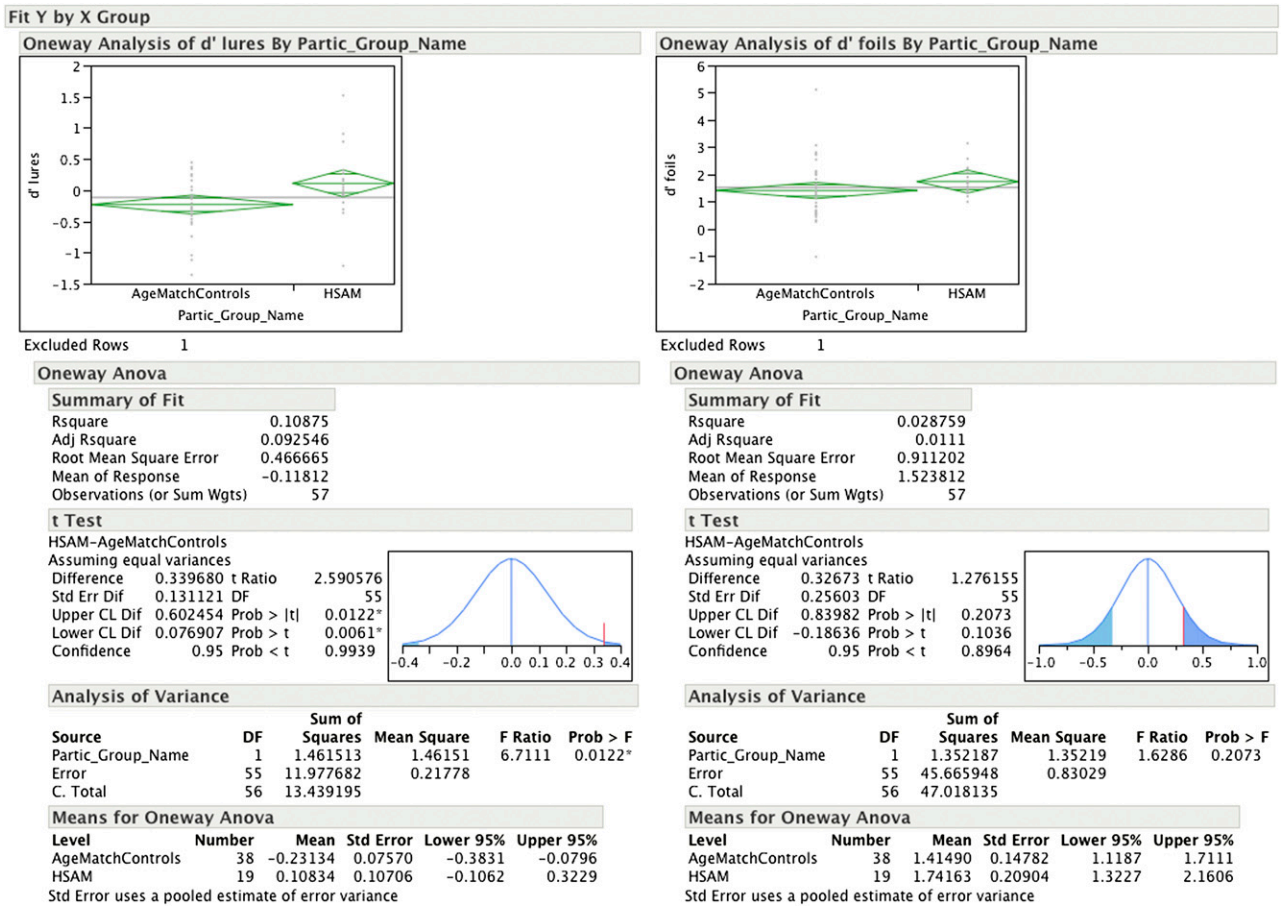

Fig. S2. A signal detection analysis of DRM using critical lures as false alarms (*Left*) and unrelated distractors as false alarms (*Right*). Although HSAM participants and controls did not differ on overall rates of critical lure endorsement on the DRM task, signal detection analysis using d' indicated that HSAM individuals were in fact better able to discriminate between hits and critical lures. HSAM participants had significantly higher d' scores than controls, $t(55) = 2.59$, $P = 0.012$ (*Left*). Using the unrelated distractors as false alarms (*Right*), there is no difference in discrimination between HSAM individuals and controls.

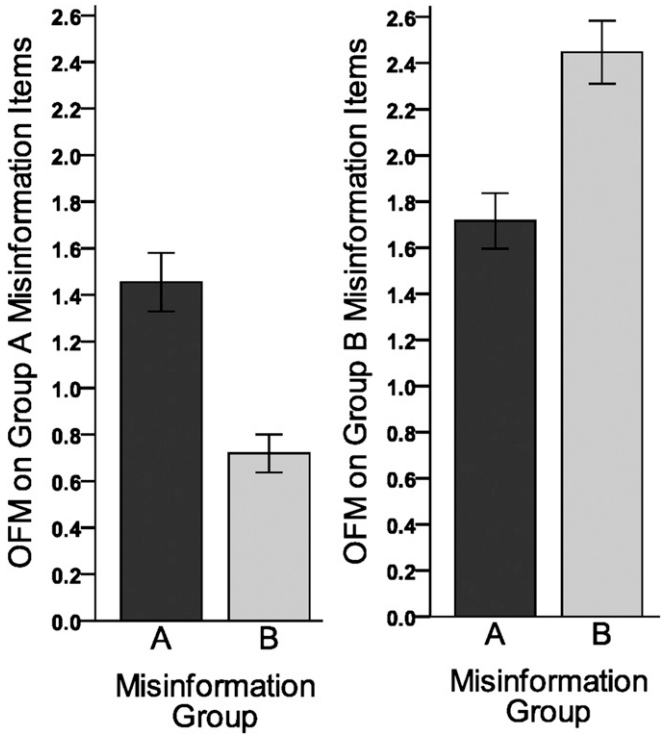

Fig. S3. The classic misinformation-effect experiment replication: The misinformation paradigm involved the random assignment of participants into one of two groups, A and B. Group A received misinformation on a different set of six items than group B, such that each group served as a control group for the other on six items, and as the experimental group on another six items. Both group A items and group B items replicated the classic misinformation effect ($Ps < 0.01$). Group B items had a stronger effect overall, so for other comparisons we removed the variance (noise) because of this difference by creating a *z*-adjusted (*z*-score calculated within each group A and B) measure for OFM (OFM_z) and SCFM ($SCFM_z$). This adjustment was taking into account in the main analysis, but had no effect in most of the statistical tests. Error bars represent SEs.

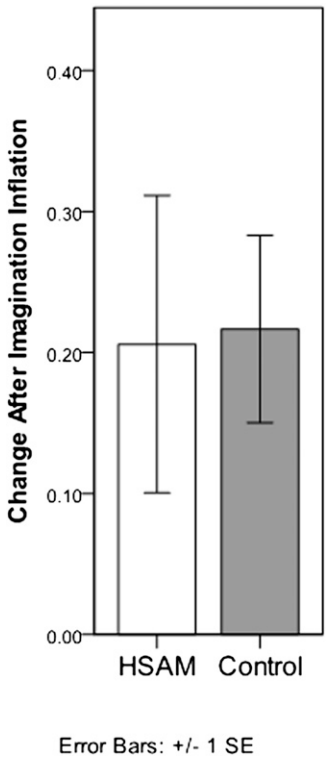

Fig. S4. Imagination inflation exercise: The mean change in certainty (from before the imagination exercise to after) of having seen the nonexistent crash footage of United 93. "Yes" was coded 1, "maybe" coded 0.5, and "no" coded 0. The increase in certainty of having seen the footage in HSAM participants (M = 0.21, SD = 0.44) was not statistically different from controls [M = 0.22, SD = 0.36), $t(45) = -0.09$, $P = 0.928$]. A 2 × 3 categorical analysis found no significant differences between HSAM individuals and controls on susceptibility to imagination inflation (Fisher's exact test: $P = 0.544$). About 17% of HSAM individuals and 10% of controls flipped from saying "no" they hadn't seen the footage before the guided imagery to "yes" after the exercise. Error bars represent SEs.

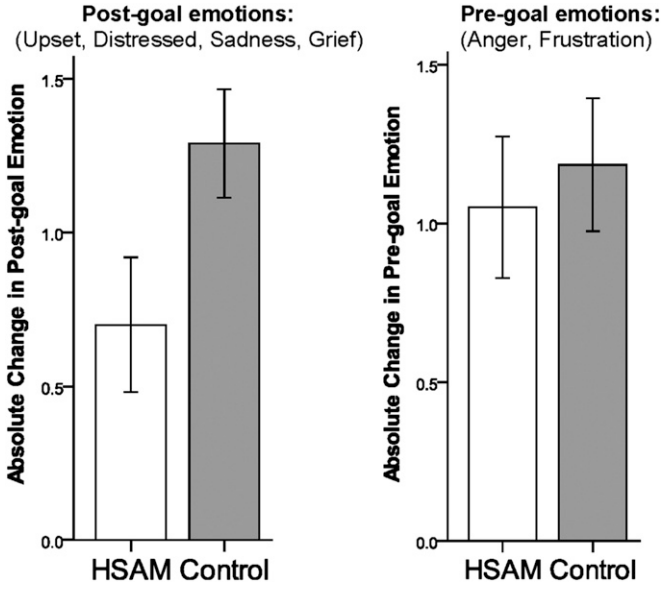

Fig. S5. Memory for emotions felt in the week after 9/11: Inconsistency from session 1 to session 2. HSAM participants and controls had nonzero consistency, from sessions 1–2, in their memory for how often they felt a number of negative emotions in the week following September 11, 2001. HSAM individuals were statistically significantly more consistent than controls at remembering postgoal emotions such as sadness (*Left*), but equally as inconsistent in their memory for pregoal emotions, such as anger (*Right*). Postgoal emotions are associated with a sense of finality and a lack of power. Pregoal emotions are associated with a sense of control and power over a situation and HSAM participants may be less consistent on those because the perceived ability to manipulate the goal can vary and cause current reappraisals. In a secondary analysis treating changes of one point as meaningless, and counting only changes of two points or more, HSAM individuals and controls were statistically similar in their absolute emotion memory change on postgoal ($M_{HSAM} = 0.85$, $M_{control} = 1.22$; $P = 0.245$) and pregoal emotion ($M_{HSAM} = 1.08$, $M_{control} = 1.26$; $P = 0.822$). Error bars represent SEs.

Table S1. Summary of each HSAM participants' autobiographical memory test scores and memory distortions in the various paradigms used in this study

	Autobiographical test scores				Memory distortion measures						
Subject no.	PEQ score	10DQ score	AMT veri.	AMT total	DRM words	Misinfo. OFM	Misinfo. SCFM	Crash quest.	Crash interview	Imagination inflation	Emotion memory
1	73.9	86.7	26	130	20[a]	3	2	No	No	No	20
2	70.5	87.5	—	—	16	3	3	Yes	Yes	—	19
3	64.8	100.0	33	156	18	4	2	No	No	Yes	14
4	53.4	89.8	26	214	17	3	0	No	No	No	23
5	73.9	93.3	34	206	8	3	1	No	No	No	15
6	51.1	75.5	—	—	12	1	1	No	No	No	35
7	67.0	100.0	47	117	20	5	1	No	No	No	11
8	56.8	80.0	22	144	16	2	0	No	No	Maybe	10
9	52.3	82.0	—	—	17	0	0	No	No	No	1[b]
10	59.1	93.8	38	126	11	5	1	No	No	No	15
11	65.9	93.3	—	—	12	1	0	No	No	No	27
12	50.0	93.3	—	—	11	4	3	No	No	No	26
13	58.0	100.0	36	225	20	2	0	Yes	No	Yes	12
14	68.2	86.2	—	—	10	0	0	No	No	Yes	12
15	65.9	76.7	—	—	14	3	3	Yes	Yes	—	18
16	63.6	83.3	—	—	12	3	1	No	No	No	15
17	67.1	100.0	—	—	10	5	0	Yes	Maybe	—	7
18	51.0	96.7	—	—	15	1	0	No	No	No	12
19	60.0	89.3	—	—	14	2	0	No	Maybe	No	24
20	50.0	70.0	—	—	14	3	1	No	No	Maybe	48

AMT total, Autobiographical Memory Test total score; AMT ver, Autobiographical Memory Test for verifiable details (1); Crash interview, participant's answer in the interview to the question "have you seen that footage" of the actual crash of United 93; Crash quest., Whether participants indicated they saw the United 93 plane crash footage in the computer questionnaire (yes/no choice); DRM words, critical lures recognized of 20 in the word list task; Emotion memory, memory for emotion for the week after 9/11—absolute overall inconsistency from week 1 to week 2 (14 negative emotions with Likert-like scale ranging from 1 = *never* to 10 = *all of the time*); Imagination inflation, answer as to whether they believe they have seen the nonexistent United 93 crash footage after the imagination exercise in the interview; Misinfo OFM, overall false memory of six in the misinformation paradigm; Misinfo SCFM, source-confirmed false memory of six in the misinformation paradigm. Em-dashes (—) indicate not tested.

[a]Did not comply apparently with DRM instructions. Participant indicated at test all words as recognized.

[b]This participant was a child at the time of September 11th, 2001, and we found floor effects; low scores on the emotion memory measures in both sessions 1 and 2, contributed to the apparent consistency.

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Table S2. Hierarchical linear regression with OFM as the predicted measure

	Model 1			Model 2			Model 3		
Variable	*b*	SE(*b*)	β	*b*	SE(*b*)	β	*B*	SE(*b*)	β
Group (HSAM 1, Control 0)	**0.53**[a]	**0.22**	**0.30**	0.44[b]	0.24	0.25	0.35[c]	0.25	0.20
Fantasy proneness (CEQ)				0.03	0.02	0.17	0.002	0.03	0.01
Absorption (TAS)							0.01	0.009	0.23
Constant	−0.08	0.13		−0.32	0.23		−0.81	0.50	
F(df)	**5.44 (1, 56)**			**3.57 (2, 55)**			**1.85 (3, 54)**		
ΔR^2		0.09			0.03			0.02	
$R^2_{adjusted}$		0.07			0.08			0.09	
VIF_{max}		1.00			1.11			2.71	

CEQ, Creative Experience Questionnaire (aka fantasy proneness); TAS, Tellegen Absorption Scale; VIF_{max}, largest variance inflation factor in a given model. Does the difference between HSAM participants and controls on OFM remain statistically significant when controlling for fantasy proneness (CEQ) and absorption (TAS)? Statistics in bold are statistically significant at $P < 0.05$. [a]$P = 0.023$. [b]$P = 0.07$. [c]$P = 0.17$. On the measures of absorption and fantasy proneness of HSAM individuals were significantly higher than controls. CEQ: $M_{HSAM} = 11.3$, SD = 4.5, $M_{control} = 8.1$, SD = 4.8, $t(56) = 2.42$, $P = 0.019$. TAS: $M_{HSAM} = 90.4$, SD = 19.9, $M_{control} = 72.6$, SD = 16.9, $t(56) = 3.57$, $P = 0.001$. First row: model 1 mimics the OFM *t* test between HSAM participants and controls described in the main article; models 2 and 3 show that the significant difference between HSAM individuals and controls goes away when controlling for fantasy proneness and absorption, with absorption having the biggest effect (see βs in model 3).