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A Cognitive Assessment of Highly Superior Autobiographical Memory

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Abstract

Highly Superior Autobiographical Memory (HSAM) is characterized as the ability to accurately recall an exceptional number of experiences and their associated dates from events occurring throughout much of one's lifetime. The source of this ability has only begun to be explored. The present study explores whether other enhanced cognitive processes may be critical influences underlying HSAM abilities. We investigated whether enhanced abilities in the domains of verbal fluency, attention/inhibition, executive functioning, mnemonic discrimination, perception, visual working memory, or the processing of and memory for emotional details might contribute critically to HSAM. The results suggest that superior cognitive functioning is an unlikely basis of HSAM, as only modest advantages were found in only a few tests. In addition, we examined HSAM subjects' memory of the testing episodes. Interestingly, HSAM participants recalled details of their own experiences far better than those experiences that the experimenter shared with them. These findings provide additional evidence that HSAM involves, relatively selectively, recollection of personal, autobiographical material.

Keywords

autobiographical memory; Highly Superior Autobiographical Memory; episodic memory; cognitive assessment; neuropsychology

Introduction

Individuals with Highly Superior Autobiographical Memory (HSAM) are able readily and accurately to recall the dates, days and many of the details of personal experiences that occurred even decades previously (Parker, Cahill, & McGaugh, 2006; LePort et al., 2012,

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A.K.R. LePort, S.M. Stark, J.L., McGaugh, and C.E.L. Stark are the authors of this article and are responsible for its content. A.K.R. LePort developed the study concept. All authors contributed to the study design and interpretation. Testing, data collection, and data analysis were performed by A.K.R LePort under the supervision of C.E.L. Stark and J.L. McGaugh. A.K.R LePort drafted the manuscript, S.M. Stark, J.L. McGaugh, and C.E.L. Stark and provided critical revisions. All authors approved the final version of the manuscript for submission.

Conflict of Interest Statement
The Authors declare that there is no conflict of interest.

LePort et al., in press). HSAM appears to differ from all other documented cases of superior memory, as there is no evidence that HSAM individuals use explicit mnemonic techniques and they do not demonstrate behavior indicative of a savant syndrome (Luria & Tsvetkova, 1968; Hunt & Love, 1972; Ericsson, Delaney, Weaver, & Mahadevan, 2004; Treffert, 2009; Foer, 2011). The findings to date suggest that HSAM's exceptional ability is restricted primarily to their autobiographical experiences (Parker, Cahill, & McGaugh, 2006; LePort et al., 2012).

Since the publication of the first case-study report of an individual with HSAM (Parker et al., 2006), we have identified additional individuals who have the same exceptional ability to recall their autobiographical experiences. After first documenting HSAMs' strong memory ability, we investigated the cognitive processes related to memory that may contribute to HSAM (LePort et al., 2012). There is extensive evidence that many cognitive processes, including attention, inhibition, working memory, and perception are crucial to the formation and retrieval of autobiographical memories (Conway et al., 1999; Greenberg & Rubin, 2003; Rubin, 2005; Berryhill, Phuong, Picasso, Cabeza, & Olson, 2007; Cabeza, 2008). We sought to evaluate whether ability in any of these domains might be significantly elevated in HSAM and thus support their exceptional memory ability. In previous research, we found that HSAM individuals were slightly, but significantly, superior in face-name associations, paragraph recall, and a visual memory task (LePort et al., 2012). In contrast, HSAMs did not differ from controls on digit span, visual reproduction, and word-pair memory. Here, we explored cognitive performance in a larger cohort of HSAM subjects, by administering a more comprehensive cognitive battery that assessed a broad range of cognitive processes, including verbal fluency, attention/inhibition, executive functioning, mnemonic discrimination, perception, visual working memory, and the processing of emotional details over time. The range of areas was intentionally very broad. It covered a wide range of cognitive functions known to be related to autobiographical memory in some way, so that the assessment might reveal any potential sources of their exceptional ability. In addition, we also chose tasks that explore further the areas in which they have previously performed somewhat better than controls (LePort et al., 2012).

Specifically, we employed a more comprehensive face-name task (Rentz et al., 2011; Amariglio et al., 2012) that includes occupations along with two encoding conditions: one that emphasizes relating the face-name-occupation to personal information ("relate this person to someone that you know") and one that encourages more objective learning ("rate the congruency of each face-name-association"). If HSAMs automatically employ a relational strategy as a fundamental basis for their ability, then instructing controls to use such a strategy should lead to an elevation of their performance to levels more commensurate with those of HSAMs.

Previous findings suggest that the strength of recollection of an event is heavily correlated with the vividness of its visual imagery (Rubin, 2005). As HSAM participants are able to report significantly more details of autobiographical memories and previously viewed images (LePort et al., 2012), it is possible that visual imagery is enhanced in HSAM. Therefore, we included a mental imagery task, a visual patterns task, and a progressive silhouettes task to further investigate this possibility. Recalling details of autobiographical

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episodes may also reflect directed attention and inhibition of irrelevant materials. Therefore, we included the Stroop task (Stroop, 1935), in which color names are presented in incongruent colors to evaluate these skills in a non-autobiographical task.

As HSAMs demonstrated improved paragraph recall in our prior work, we included a script generation task to investigate further whether HSAMs exhibit superior narrative skills. It is possible that an increased ability to produce verbal narratives may lead to a richer personal narrative that HSAMs encode and later retrieve. Additionally, to investigate whether emotionally driven narratives might underlie the autobiographical events that are later retrieved, we included the Three-Phase Story (Heuer & Reisberg, 1990; Cahill & McGaugh, 1995) used in previous studies reporting enhanced recall of the central information in an emotionally arousing story, but not peripheral details. We investigated whether HSAMs, who are likely to remember both central and peripheral details of their own autobiographical memories, might demonstrate enhanced recall of peripheral details in the Three-Phase Story.

Similarly, we administered the Mnemonic Similarities Task (Stark et al., 2013) to investigate whether attention to detail may result in greater discrimination of similar lures. In this task, recognition memory is probed with repeated items, novel foil items, and related lure items, which are similar to studied items, but differ in details. As the ability to mnemonically distinguish similar lures from repeated items declines with age (Stark et al., 2013; 2015) and is selectively impaired in amnesic patients (Kirwan et al., 2012), we investigated whether HSAMs, with their heightened ability to distinguish between highly overlapping autobiographical memories, might also demonstrate increased lure discrimination in this task.

Finally, we hypothesized the HSAMs might use a grouping strategy to encode and recall their autobiographical memories more effectively, so we tested this performance on the California Verbal Learning Test (CVLT; Delis, Kramer, Kaplan et al., 1987). In this task, a list of 16 words is presented in a random order, each of which belongs to one of four categories (e.g. fruits, clothing). Whereas the participant is not instructed to use the category information, recall is usually higher for those who utilize the category structure during encoding and recall. If HSAMs use a categorization strategy for their autobiographical memories, they might demonstrate enhanced performance on this task.

In addition to assessing HSAMs' cognitive abilities, we investigated their memory for autobiographical episodes that varied in the amount of personal content by testing their recollection of participation in the testing experience, referred to here as a "Meta-Test." Experiences covered in the Meta-Test were graded in terms of the degree of relationship to the participant's life (e.g., recall of the time and order of the cognitive tests, and recall of previously discussed events, either their own or the experimenter's information). If HSAM reflects a broad and general ability to recall autobiographical material, HSAM participants should outperform controls on all aspects of the Meta-Test with no discrepancy between performances on each of the tests (e.g., personal autobiographical aspects vs. more general aspects of the testing session). In contrast, if HSAM is restricted to the enhancement of self-referential processes, HSAM participants should perform best on aspects of the test that are most relevant to their own life.

Materials and Methods

All experiments reported here were carried out in accordance with the Institutional Review Board (IRB) at the University of California, Irvine, and were consistent with Federal guidelines. A multi-step, Institutional Review Board (IRB) approved process was developed to identify and test HSAM and control participants. Potential HSAM participants contacted us following media coverage of HSAM, which has been featured on *60 Minutes* and from other media outlets. These individuals were screened using the Public Events Quiz and 10 Dates Quiz (LePort et al., 2012). Briefly, the Public Events Quiz contained two types of questions: half asked for the date of a given significant public event that took place within the individuals' lifetime (e.g., When did Jimmy Carter win the Nobel Peace prize?) and the other half asked for the significant public event that took place on a given date that fell within the individual's lifetime. In addition, for all 30 questions, individuals were asked to state the day of the week the date fell on. The order of presentation of the two types of questions was interchanged. Participants receive 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 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. This score corresponds to roughly the mean of the second, higher component of a markedly bimodal distribution of scores from respondents (the other component having a mean of 13%; LePort et al., 2012).

The 10 Dates Quiz consisted of ten computer generated random dates, ranging from the individuals' age of fifteen to the day of testing. Individuals were asked to provide three different categories of information for each of the 10 dates generated: (1) the day of the week; (2) a description of a verifiable event (i.e. any event that could be confirmed via a search engine) that occurred within ± one-month of the generated date; and (3) a description of a personal autobiographical event the individual participated in. One point each was awarded for the correct day of the week, for giving a verifiable event confirmed as true, and/or for giving a personal autobiographical event. A maximum of three possible points per date could be achieved (thirty points total). The percentage scored for each category as well as the total score, the average of all three categories, was calculated. A total score of 65% or above qualified the individual as an HSAM participant. Performance on these screening tests correlates highly with verifiable autobiographical recall, making them a useful proxy for screening exceptional autobiographical memory recall. While these screening measures focus on nonautobiographical events, memory of these public events are often tied to the autobiographical experiences in these HSAM participants, resulting in much greater recall in the HSAM group than controls.

Twenty HSAM participants (13M/7F, average age 37.5 (20–53), average years of education = 16.3 (12–20)) were matched by sex and age to twenty-two controls (13M/9F, average age 43.9 (19–63), average years of education = 15.3 (13–18) recruited through advertisements from the community. Five of the HSAM participants and none of the controls also completed the cognitive battery reported in Leport et al. (2012). Five HSAM and eight control participants failed to complete various parts of this cognitive battery, so the number of participants who completed each subtest is reported in the Results section. All participants received $15 per hour for their participation.

As the HSAM participants are located across the country, all behavioral tests were remotely administered using Google Hangouts or Skype. Four sessions were scheduled on consecutive Monday, Wednesday, Friday, and Monday dates. Each session was recorded for reference and later transcribed. There were two types of behavioral tests administered: 1) A cognitive battery, consisting of eight tasks assessing elaborative processing, verbal fluency, attention and inhibition, executive functioning, mnemonic discrimination, perception, visual working memory and the processing of emotional details. 2) A surprise "Meta-Test" assessing the autobiographical recollection of details related to the cognitive battery, the participant's life and also the researcher's life. The Meta-Test was given on the last day of testing (the second Monday) and again approximately one-month later. Thus, participants were tested for information acquired/discussed 3, 5, and 7 and again 27, 29, & 31 days prior.

Face-Name-Occupations Task

Associative memory was assessed with a modified version of the Face Name Associative Memory Exam (Rentz et al., 2011b; Amariglio et al., 2012) in 17 HSAM and 17 control participants. Participants were required to learn two sets of 16 unfamiliar face-name (F-N) and 16 unfamiliar face-occupation (F-O) pairs. Consistent with the FNAME procedure, participants were first exposed to a set of 16 faces before studying the 16 F-N pairs. After a single study, they were given an initial cued-recall test by being given the face and asking for the name. They were then given the same 16 faces, now associated with an occupation to study and subsequently given an *initial cued recall* test for this information in the same manner. During the study phases, participants were asked to make one of two judgments. In the "Rating" condition, participants viewed unfamiliar faces and rated how congruent the 16 F-N and 16 F-O associations were on a scale of 1–7. In the "Scenario" condition (using the other set of 16 face-name-occupation associations), participants were told to relate the 16 F-N and 16 F-O associations to someone they knew. Again consistent with the FNAME task, following the full face-name and face-occupation study and initial tests, we administered the *immediate cued-recall test phase* (removing the FNAME's *immediate free recall task* for brevity). Here, all of the 64 paired-associates that formed the face-name-occupation (F-N-O) associations were tested. Approximately 20-minutes and 96 hours later the F-N-O cued recall test was repeated for the *delayed cued-recall* test. The order of the 64 F-N-O pairs and phases were randomized, ensuring independence of results for the order of presentation and study condition (rating vs. scenario). Correct associations were given one point. Points were summed to arrive at a F-N and F-O score for each phase and F-N-O scores for each delay time point.

Mental Imagery Task

The efficiency by which participants assigned novel interpretations to ambiguous images was assessed with the Mental Imagery Task (Finks, Pinker, & Farah, 1989). 18 HSAM and 17 control participants were asked to mentally combine 6 pairs of different symbols or shapes and report as many emergent forms as they could. For example, when asked to imagine the letter "D" on its side, affixed to the top of the letter "J", subjects might report

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"seeing" an umbrella. They were then asked to draw their imagined image and report any additional forms they may have missed when only imagining it. The type of emergent forms reported (geometric or symbolic), the medium by which it was revealed (imagination vs. drawing) and the number of accurate figures reported for each type/medium was determined based on the guidelines set forth by Finks et al. (1989). "Geometric" referred to all emergent forms that were shapes, while "symbolic" referred to other more representative forms (e.g. letters, a bookcase, a butterfly, etc.).

Visual Patterns Task

Visual short-term memory storage was assessed with the Visual Patterns (VP) task (Della Sala, Baddeley, Gray, & Wilson, 1997) in 19 HSAM and 17 control participants. Grids containing random patterns created by black and white squares were briefly shown to participants for 3 seconds each. Grids progressed in size from a 2×2 matrix (with two filled cells) to a 5×6 matrix (with 15 filled cells), with complexity steadily increasing by adding two more cells to each previous grid. Participants were instructed to recreate the pattern immediately after it was removed by marking squares of an empty grid. The number of black squares correctly recalled by each participant was recorded.

Progressive Silhouettes Task

Visuospatial ability was examined in 19 HSAM and 19 control participants using the Progressive Silhouettes task (Warrington & James, 1991). The test consists of silhouettes of 15 animals and 15 inanimate objects. Participants were asked to identify each three-dimensional object from a series of silhouettes that became progressively easier to identify. Two trials were given and participants were encouraged to guess. Participants were scored according to the number of silhouettes required to correctly identify each object. Scores were averaged across trials.

Script Generation Task

Efficiency of semantic memory retrieval, narrative skills and verbal fluency was examined using the Script Generation Task (Bower, Black, & Turner, 1979) in 18 HSAM and 20 control participants. They were instructed to list as many stereotypical actions as they could regarding four routine activities likely to be familiar to all participants: attending a lecture, going to a restaurant, visiting a doctor and shopping for groceries. "Attending a lecture" served as an exemplar in which the participant practiced and provided a script until the maximum level of detail they could provide was achieved. Importantly, participants were explicitly told to omit unique personal habits or actions. Stereotypical actions were given one point; all other actions were omitted from analysis. Points were added and averaged across the three scenarios.

Three Phase Story

Emotional intensity is known to affect the perceptual and phenomenological properties of autobiographical memories, such as the degree to which the memory is re-lived on retrieval, the vividness of the memory and narrative detail (Talarico, LaBar, & Rubin, 2004). The enhancement of subsequent memory retrieval, by means of emotional arousal, has been

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studied using the "Three Phase Story," a negative social-emotional story (Heuer & Reisberg, 1990; Cahill & McGaugh, 1995; Cahill, Gorski, Belcher, & Huynh, 2004; Nielsen, Ertman, Lakhani, & Cahill, 2011). Specifically, emotional arousal following comprehension of the Three Phase Story has been shown to enhance long-term memory for central information (i.e. details making up the building blocks of the fundamental story line), but not peripheral information (i.e. details describing the building blocks of the fundamental story line) in males (Cahill & van Stegeren, 2003; Cahill et al., 2004). Therefore, we excluded the female data here as our sample size for the female group was too small to be reliable. Thus, 13 male HSAM and 9 male control participants completed this task.

The Three Phase Story consisted of a sequence of 11 slides, accompanied by a taped narration, displayed in three phases (adapted from Cahill & McGaugh, 1995). The most emotional portion was phase 2, in which a boy was caught in a terrible accident and his severe injuries were displayed to the viewer. One week later, participants were given a surprise recall test to assess their ability to recollect details of the story. In this way, the effects of emotional arousal on male participants' subsequent recollection of central and peripheral information for each of the three phases could be assessed. It is worth noting that unlike the typical administration of this task, incidental encoding may not have taken place, as all participants were aware that the main function of the study was to assess memory function.

Stroop Task

The Stroop Task (Stroop, 1935; Comalli Jr, Wapner, & Werner, 1962) is classically used to assess a subject's ability to inhibit immediate, but inappropriate responses, requiring inhibition of prepotent responses, and engagement of cognitive control. It has also been used as an assessment tool for frontal lobe function (Stroop, 1935; Vendrell et al., 1995). Nineteen HSAM and 17 control participants completed a modified Stroop Task (Stroop, 1935) consisting of four phases. First, participants named the color of dots: blue, green, purple, red and brown. Second, they named colored words (font type, Calibri), each of which was printed in a color (blue, green, purple, red or brown) other than the one spelled by its letters. This served as the critical interference condition as participants had to attend to the color while inhibiting the tendency to read the word. Third, they named words (font type, Calibri), printed in black and white, spelling out different colors (blue, green, purple, red or brown). Fourth, subjects read words in which the words' color and the color they spelled out were congruent. Each phase consisted of 100 dots or words in a 10 × 10 grid. The time, in seconds, required to complete each phase of the task was recorded. Participants were instructed, for each condition, to respond as quickly as possible and be careful not to make any errors.

Mnemonic Similarity Task

Many long-term declarative memories are highly overlapping in nature, imposing a large amount of interference that must be resolved. The orthogonalization of overlapping information in memory is termed "pattern separation" (McClelland et al., 1995). We have developed a task designed to evaluate the efficacy of this pattern separation process, called the Mnemonic Similarity Task (Kirwan & Stark, 2007; Stark et al., 2013). By including highly similar lures in a recognition task, we can assess the ability of the system to preserve unique, detailed representation of the original memory. In the study phase, 19 HSAM and 14 control participants were shown 64 images of common items and asked to classify the item as belonging "indoor" or "outdoor." Subsequently, during test, participants viewed 32 repeated items, 32 related lure items, and 32 novel foils. Participants were instructed to classify each item as old (repeats), similar (lures), or new (foils). We then calculated a lure discrimination index (LDI) as the percentage of lures correctly identified as "similar" minus the percentage of foils incorrectly identified as "similar" (p("S"|L) − p("S"|F)). In addition to measuring mnemonic discrimination, traditional recognition memory was defined as the percentage of targets endorsed as "old" minus the percentage of foils endorsed as "old" (hits minus false alarms) (Stark et al., 2013).

California Verbal Learning Test

The California Verbal Learning Test (CVLT; Delis, Kramer, Kaplan et al., 1987) is a measure of verbal learning and memory used extensively in clinical neuropsychology to assess short-term and long-term memory as well as executive functioning (Delis, Massman, Butters et al., 1991). Qualitative indices of learning and memory, such as learning strategies (e.g. semantic versus serial clustering), comparisons of types of errors (e.g. intrusions and perseverations), and effects of interference on recall can be assessed using this task (Golden, Espe-Pfeifer, Wachsler-Felder, 2000). The CVLT involves the oral presentation of two sixteen-word lists (List A and B), consisting of four sets of four words from four semantic categories. Participants were given five consecutive immediate free recall trials of list A. Following these trials, the presentation and immediate free recall of the interference list (List B) was performed. The next trial involved a "short-delay" free recall and category-cued recall of List A. Following a "long-delay" (20 minutes), we tested free recall and category cued recall trials of List A. Lastly, a forced-choice recognition condition for List A was performed. Performance could be examined using 19 indices such as the number of words correctly recalled, learning strategies, and types of errors (see Table 3). In addition, we calculated a Discrimination Index on the recognition task to account for the false positive rate (recognition hits/(recognition hits + false positives)). Discrimination Index values closer to 1 reflect better performance on this task.

Meta-Test

Narrative elements for the surprise Meta-Test were interspersed throughout each of the three cognitive battery sessions occurring 3, 5 and 7 days prior. Adhering to a strict guideline, three predetermined conversations were administered on each of the three cognitive battery days. The researcher asked the participant specific questions about events in the participant's life and these shared details of events that the researcher had personally experienced. The questions asked were: "How was your weekend" (asked Monday), "How has your day been so far?" (asked Wednesday) and "What are you up to this weekend?" (asked Friday). The researcher's stories were centered around getting a new puppy (told Monday), slipping and falling in a restaurant (told Wednesday), and seeing a student with a gun on campus (told Friday).

During the Meta-Test, which occurred on the following Monday, participants were asked to recall information about the previous testing sessions, including 1) Time – the date, day of the week, and time of each of the three sessions, 2) Order – the type and order of cognitive tests taken, 3) Self – their responses to discussions had about their day and 4) Other – as many details as could be recalled about the story the researcher shared about herself. Each question pertained to an experience occurring 3, 5 and 7 days prior. One month later, all participants were given an online retest, using SurveyMonkey, consisting of these same questions listed above.

Results reflect scores for correct information obtained approximately 3, 5, 7, 27, 29, and 31 days prior. Recorded were: 1) The number of correct dates, days of the week, and times given. Responses scored a ‘1’ if all three items were correct or a ‘0’ if any of the three items were incorrect. 2) The number of correct responses given to questions about the participant’s life. Data relating to the three questions asked were referred to as “question.” If the participant could not recall the question, a prompt was given. If the participant recalled their original response, 1 point was given. If a prompt was not needed, the score was doubled. 3) The percentage of correct details recalled (out of total details originally given by the researcher) from the story about the researcher. Data relating to the three stories told were referred to as “story.” This score was inflated in the same manner as the “question” score, by doubling it, if a prompt to remember the story was not needed. 4) The percentage of correct tests recalled in their proper order for each day. 18 HSAM and 15 control participants completed the “Time”, “Order” and “Self” portions of the Meta-test, while 17 HSAM and 15 control participants completed the “Other” portion of the test.

Results

Face-Name-Occupations Results

Fifteen controls and 15 HSAMs completed the Face-Name-Occupations task. HSAM participants were modestly superior to controls in their ability to recall faces and their associated names and occupations in the initial face-name task (directly after study). The number of correct responses by HSAMs and controls in the Face-Name and Face-Occupation initial test are presented in box and whisker plots (Figure 1a). A 2×2×2 repeated measures ANOVA of group (HSAM vs. Control) by study task (rating vs. scenario) by information type (name vs. occupation) as independent factors revealed a significant main effect of group ($F_{(1,32)} = 7.34$, $p = 0.011$, $\eta_p^2 = 0.17$), with HSAMs ($M = 9.96$, $SD = .85$) recalling more face-name and face-occupation associations than controls ($M = 7.47$, $SD = .84$). Likewise, there was a main effect of task ($F_{(1,32)} = 9.19$, $p = 0.005$, $\eta_p^2 = 0.22$), with greater recall for the rating encoding task ($M = 9.50$, $SD = .87$) than the scenario encoding task ($M = 7.93$, $SD = .82$). Finally, there was a main effect of information type ($F_{(1,32)} = 15.04$, $p < 0.001$, $\eta_p^2 = 0.32$), with greater recall for occupations ($M = 9.69$, $SD = .70$) than names ($M = 7.73$, $SD = .99$). Importantly, while the two-way interaction of task × type was significant ($F_{(1,32)} = 5.72$, $p = 0.023$, $\eta_p^2 = 0.15$), no two-way interactions with groups were significant: group × task ($F_{(1,32)} = 0.77$, $p > 0.250$, $\eta_p^2 = 0.02$) and group × type ($F_{(1,32)} = 0.04$, $p > 0.250$, $\eta_p^2 = 0.00$). There was also no significant three-way interaction of group × task × type ($F_{(1,32)} = 0.19$, $p > 0.250$, $\eta_p^2 = 0.01$). Contrary to our predictions, controls were not able to elevate their performance comparable to that of HSAMs by using the scenario encoding task, which linked the studied information to existing knowledge.

We further evaluated performance in the immediate and delayed tests that followed the completion of the study phase (Figure 1b). A 2×2×3 repeated measures ANOVA of group (HSAM vs. Control) by encoding task (rating vs. scenario F-N-O) by delay (immediate, 20 minute, 96 hours) as independent factors revealed a significant main effect of group ($F_{(1,28)} = 7.97$, $p = 0.009$, $\eta_p^2 = 0.22$), with greater recall for HSAMs (13.9) than controls (9.6). We also found a main effect of delay ($F_{(1,28)} = 31.91$, $p < 0.001$, $\eta_p^2 = 0.53$), with greater recall for immediate testing (13.0) than a 20-minute delay (12.8) than a 96-hour delay (9.6). Here, we found no main of encoding task ($F_{(1,28)} = 0.68$, $p > 0.250$, $\eta_p^2 = 0.024$). Likewise, no two-way interactions were significant: group × task ($F_{(1,28)} = 3.04$, $p = 0.09$, $\eta_p^2 = 0.10$), group × time ($F_{(1,28)} = 0.01$, $p > 0.250$, $\eta_p^2 = 0.00$), time × task ($F_{(1,28)} = 0.01$, $p > 0.250$, $\eta_p^2 = 0.00$), nor was there a significant three-way interaction of group × time × task ($F_{(1,28)} = 0.25$, $p > 0.250$, $\eta_p^2 = 0.01$). Thus, HSAM participants outperformed controls on recalling faces-name and face-occupation associations in both encoding task conditions. Interestingly, for both tasks and both groups, performance dropped equally with the passage of time.

Mental Imagery Results

Seventeen HSAM and 18 control participants performed comparably on the Imagery task. The number of accurate figures reported for each type (geometric vs. symbolic) and task (imagination vs. drawing) was compared between groups. A 2×2×2 repeated measures ANOVA of group (HSAM vs. Control) by task (imagination vs. drawing) by type (symbolic vs. geometric) revealed significant main effects of task ($F_{(1,33)} = 133.70$, $p < 0.001$, $\eta_p^2 = 0.80$), with more accurate items reported for imagination (M = 2.33, SD = 1.07) than drawing (M = .68, SD = .68). There was also a main effect of type ($F_{(1,33)} = 27.27$, $p < 0.001$, $\eta_p^2 = 0.45$), with more accurate items reported for symbolic items (M = 1.07, SD = 1.10) than geometric items (M = 1.94, SD = .65). Critically, there was no main effect of group ($F_{(1,33)} = 0.77$, $p > 0.25$, $\eta_p^2 = 0.02$). HSAMs and controls performed all task conditions comparably. While the two-way interaction of type × task was significant ($F_{(1,33)} = 82.25$, $p < 0.001$, $\eta_p^2 = 0.71$), no other two-way interactions were significant: group × type ($F_{(1,33)} = 0.03$ $p > 0.25$, $\eta_p^2 = 0.00$) and group × task ($F_{(1,33)} = 1.02$, $p > 0.25$, $\eta_p^2 = 0.03$). There was also no significant three-way interaction of group × type × task ($F_{(1,33)} = 0.09$, $p > 0.25$, $\eta_p^2 = 0.00$). Thus, the HSAM's performance on this task did not differ from that of controls, suggesting that superior mental imagery may not contribute to their superior autobiographical memories.

Visual Patterns & Progressive Silhouettes Results

Nineteen HSAM and 17 control participants performed similarly on the Visual Patterns task and Progressive Silhouettes task. The mean Visual Patterns score for HSAM participants (M = 6.32, SD = 1.57) did not significantly differ from that of controls (M = 6.35, SD = 1.32) (two-tailed Mann-Whitney, $p > 0.25$, $r = -0.01$). Likewise, HSAM (M = 7.66, SD = 2.07) and control (M = 6.95, SD = 2.22) participants also performed similarly on the Progressive Silhouettes task (two-tailed Mann-Whitney, $p = 0.14$, $r = 0.16$). Taken together, the results of the Mental Imagery, Visual Patterns, and Progressive Silhouettes tasks did not provide any evidence for superior visual processing or attention to visual detail by HSAMs.

Script Generation Results

Twenty HSAM participants outperformed 20 controls on the Script Generation task (Figure 2). The mean number of stereotypical actions reported from the three routine activities, from HSAM participants ($M = 17.81$, $SD = 8.20$) was significantly greater than that of controls ($M = 13.55$, $SD = 4.82$) (two-tailed Mann-Whitney, $p = 0.003$, $r = 0.30$). Consistent with our hypothesis, these data indicate that HSAMs are able to provide a richer script narrative, which may support detailed encoding of their autobiographical episodes.

Three Phase Story Results

The Three Phase Story measured the effects of emotional arousal on memory retention in 13 male HSAM and 9 male control participants (Figure 3a). A two-way repeated measures ANOVA with group (HSAM vs. Control) and phase (1–3) as independent factors and number of *peripheral details* as the dependent factor revealed a significant main effect of phase ($F_{(2,40)} = 12.56$, $p < 0.001$, $\eta_p^2 = 0.39$) and a significant interaction ($F_{(2, 40)} = 4.75$, $p = 0.014$, $\eta_p^2 = 0.19$), but no main effect of group ($F_{(1,20)} = 0.63$, $p > 0.250$, $\eta_p^2 = 0.05$). Bonferroni-corrected multiple comparisons revealed greater recall of peripheral details for controls ($M = 4.67$, $SD = 4.89$) than HSAMs ($M = 1.46$, $SD = 2.47$) during Phase 2 ($t_{(60)} = 2.46$, $p < 0.05$). HSAM and control participants recalled similar numbers of central details from all three phases (Figure 3b). A two-way repeated measures ANOVA with group (HSAM vs. Control) and phase (1–3) as independent factors and number of *central details* as the dependent factor revealed a significant main effect of phase ($F_{(2,40)} = 40.88$, $p <0.001$, $\eta_p^2 = 0.67$), with a greater number of details for Phase 1 ($M = 3.4$, $SD = .01$) than Phase 2 ($M = 3.06$, $SD = 2.3$) than Phase 3 ($M = .35$, $SD = .49$). However, there was no main effect of group ($F_{(1,20)} = 0.60$, $p > 0.250$, $\eta_p^2 = 0.03$) or interaction ($F_{(2, 40)} = 0.98$, $p > 0.250$, $\eta_p^2 = 0.05$). In contrast to our predictions, HSAMs did not show an increase in retention of details during Phase 2 (i.e., the phase in which "emotional stimuli" were presented). Instead, HSAM participants recalled fewer peripheral details from the second phase in comparison to controls.

Stroop Task Results

Nineteen HSAM and 17 control participants performed similarly on the Stroop task. We compared the mean time to complete each of the four conditions within the Stroop task between groups and across conditions (Table 1). Two-way repeated measures ANOVA with group (HSAM vs. Control) and phase (1–4) as independent factors revealed that both HSAMs and controls completed the four different phases at different rates ($F_{(3,102)} = 229.50$, $p < 0.001$, $\eta_p^2 = 0.87$). There was no significant main effect of group ($F_{(1,34)} = 0.07$, $p > 0.250$, $\eta_p^2 = 0.004$) or interaction of group × phase ($F_{(3, 102)} = 0.29$, $p > 0.250$, $\eta_p^2 = 0.01$). Thus, HSAMs were no better than controls at inhibiting incongruent information and or attending only to the critical information in this task

Mnemonic Similarity Task Results

Nineteen HSAM and 14 control participants performed similarly on both metrics calculated in the Mnemonic Similarity Task. The lure discrimination index (LDI) was comparable in both controls (M = 29.39, SD = 15.59) and HSAMs (M = 21.40, SD = 19.24), two-tailed Mann-Whitney, $p = 0.222$, $r = -0.222$. Likewise, recognition memory was comparable in both controls Neither the LDI nor recognition scores significantly differed from controls (M = 70.73, SD = 7.50) and HSAMs (M = 65.07, SD = 10.95), two-tailed Mann-Whitney, $p = 0.183$, $r = -0.30$. Findings provide no evidence for increased pattern separation ability in HSAMs.

California Verbal Learning Task Results

Seventeen HSAM and 19 controls completed the CVLT. We calculated 19 indices of the CVLT (Table 2) based on the criteria set forth by Delis et al. (1988). A two-way repeated measures ANOVA of group by task revealed a significant interaction ($F_{(18, 612)} = 7.20$, $p < 0.001$, $\eta_p^2 = 0.17$), a main effect of task ($F_{(18, 612)} = 776.40$, $p < 0.001$, $\eta_p^2 = 0.95$), but no effect of group ($F_{(1, 34)} = 0.23$, $p > 0.250$, $\eta_p^2 = 0.00$). Post-hoc t-tests (Bonferroni corrected for multiple comparisons) revealed that HSAM participants scored significantly higher on List A total recall ($t(646) = 3.18$, $p < .01$), while controls scored significantly higher on Percent Primacy Recall ($t(646) = 3.30$, $p < .01$) and Consistency of item recall ($t(646) = 9.65$, $p < .01$) (Table 2). With the exception of slightly better total recall, HSAMs did not show improved performance on word list recall and did not appear to take special advantage of the category relatedness compared to controls.

Meta-Test Results

Mean performance for 18 HSAMs and 15 controls for each of the four measures of the Meta-Test are presented in Figure 4. HSAM participants were better able to recall when a cognitive session took place (date, day of the week, and time) in comparison to controls (Figure 4A). A two-way repeated measures ANOVA factors revealed significant main effects of group ($F_{(1,31)} = 27.66$, $p < 0.001$, $\eta_p^2 = 0.29$), with greater performance for HSAMs than controls. There was also a main effect of delay ($F_{(5,155)} = 8.17$, $p < 0.001$, $\eta_p^2 = 0.21$), with greater performance at the earlier time points than the more remote ones and a significant interaction ($F_{(5,155)} = 4.34$, $p < 0.001$, $\eta_p^2 = 0.12$). We applied a linear regression, which determine that the slopes (forgetting rates) differed significantly between groups ($p < 0.001$, $r^2 = 0.27$); HSAM participants (slope = − 0.002, SEM = 0.002) and controls (slope = −0.02, SEM = 0.004). Thus, HSAMs recall of the timing of the tests was maintained exceptionally well across all time points, whereas the memory for this information dropped from the recent time points to the remote ones for controls.

The memory for the order of tests taken during the cognitive battery was largely similar for HSAMs and controls (Figure 4B). A two-way repeated measures ANOVA revealed a significant main effect of delay ($F_{(5, 155)} = 4.58$, $p < 0.001$, $\eta_p^2= 0.13$) showing overall forgetting over time. There was only weak evidence for any difference between groups ($F_{(1,31)} = 3.27$, $p = 0.080$, $\eta_p^2= 0.05$) and no interaction ($F_{(5,155)} = 1.68$, $p = 0.143$, $\eta_p^2= 0.05$). Thus, HSAMs are not markedly better in their recall for the order of the tests.

As one might expect, HSAM participants were better able to recall their personal, autobiographical memories in the form of their previous responses to queries about their day or plans (Figure 4C). A two-way repeated measures ANOVA revealed a significant main effect of group ($F_{(1,31)}$ = 10.69, p = 0.002, η_p^2 = 0.18), with greater recall for HSAMs than controls. Interestingly, there was no main effect of delay ($F_{(5, 155)}$ = 0.56, p > 0.250, η_p^2 = 0.02) or interaction ($F_{(5,155)}$ = 0.56, p > 0.250, η_p^2 = 0.02). HSAMs' performance was better than controls at all time points when recalling personal, autobiographical events that were earlier shared.

The researcher (AL) shared three of her own experiences with the participants at the same time. For these details, that are not personal or autobiographical in nature for the participant, HSAMs showed no signs of elevated performance (Figure 4D). A two-way repeated measures ANOVA revealed a reliable main effect of delay ($F_{(5, 150)}$ = 2.29, p = 0.049, η_p^2= 0.07), with a slight decline in details recalled over time. However, there was no significant main effect of group ($F_{(1,30)}$ = 0.02, p > 0.250, η_p^2= 0.00) and no interaction ($F_{(5,150)}$ = 0.12, p > 0.250, η_p^2= 0.00). In contrast to information relating to the self, HSAMs and controls did not differ in the amount of information recalled about another person's autobiographical information.

Discussion

We investigated cognitive performance in a cohort of HSAM subjects by administering a cognitive battery that assessed a broad range of cognitive processes including verbal fluency, attention/inhibition, executive functioning, mnemonic discrimination, perception, visual working memory, and the processing of emotional details over time. We selected each task based on targeted hypotheses regarding how the assessed cognitive process may influence HSAMs recollection..

Although HSAM participants are significantly superior at the recollection of autobiographical events (LePort et al., 2012; LePort et al, 2016), their performance on many tasks in the cognitive battery was either similar to or only modestly better than that of controls (Table 3). We had hypothesized that greater visualization strategies might contribute to HSAMs' recollection of events. However, their performance on the Mental Imagery, Visual Patterns, and Progressive Silhouettes tasks was no better than that of controls. Thus, it seems unlikely that superior mental imagery contributes to their rich, detailed recollection of autobiographical events. Likewise, we hypothesized that recalling details of autobiographical episodes may reflect directed attention and inhibition of irrelevant materials or the ability to mnemonically separate related, overlapping episodes. However, HSAMs performed no better than controls on either the Stroop Task or the Mnemonic Similarity Task. Thus, the skills underlying these tasks do not contribute significantly to greater autobiographical recall in HSAM.

In contrast, in some tasks HSAMs exhibited better performance than controls and in other tasks controls performed better than HSAMs. In particular, the HSAMs excelled on the Face-Name-Occupation, Script Generation, California Verbal Learning Test, Three Phase Story, and the Meta Test. The findings from these tasks may reveal some of the underlying strengths utilized by HSAMs and applied to their autobiographical memories. However, we should note that, consistent with our prior work (LePort et al., 2012), whereas differences were observed on several tasks, the size of the effects were markedly smaller when the tasks were not overtly autobiographical in nature.

Face-Name-Occupations Task

The face-name-occupation task used here is a highly demanding recall-memory task that permits sensitivity powerful enough to tease out early impairment and preclinical Alzheimer's Disease (Rentz et al., 2011). HSAM participants demonstrated reliably superior performance on this task. These findings are consistent with previous evidence indicating an enhanced recollection of face-name associations (LePort et al., 2012). Here we found that HSAM subjects are superior on face name/occupation associations and that the enhancement is evident at both short and long delays.

We had hypothesized that HSAMs might naturally utilize a relational strategy when encoding face-name-occupation information by linking it to previous autobiographical information (e.g. relating the face-name pair to someone they already know with the same name). However, both HSAMs and controls performed better on the face-name-occupation pairs when they made a simple rating judgment than when explicitly instructed to relate the face to someone already known to them. Perhaps HSAMs automatically use a relational strategy, creating a greater depth of encoding by performing the rating task as well. The HSAMs outperformed the controls in both encoding conditions. Perhaps this face-name association enhancement is a by-product of excellent autobiographic memory or perhaps it is a skill that underlies the ability to recall people and dates from one's life. Regardless, we can conclude that enhanced face-name learning is a reliably superior skill in HSAMs.

Script Generation

A "script" has been referred to as the memory structure a person possesses before new knowledge of a situation is encoded (Schank & Abelson, 1977). The Script Generation task attempted to isolate this memory process by restricting participants' narratives to general, rather than idiosyncratic, actions. HSAMs' performance indicates that, at baseline, their storylines are reliably richer than that of controls. Because details can serve as cues that trigger even more details, such finding suggest that a richer store of semanticized actions could contribute to HSAMs' enhanced ability to recall episodic events. These data are consistent with our previous finding that HSAMs are superior at tasks involving verbal, story-based narratives (LePort et al., 2012). Perhaps they utilize a narrative structure in the recall of their own autobiographical memories. In fact, several HSAMs have reported that they actively recall the events, or story, of a given date a year ago, two years ago, three years ago, and a so on (Leport et al., 2012).

California Verbal Learning Task

The CVLT required participants to study a list of 16 words belonging to four semantic categories (animals, vegetables, ways of traveling, furniture). The four words from each category were studied five times each. The initial case study of the first HSAM participant, A.J., reported evidence of below average memory performance under free and cued recall conditions as well as poor strategy use (e.g., the use of serial clustering over semantic clustering; Parker et al., 2006). In contrast, in the present study we found that HSAMs' performance was generally comparable to that of controls. However, they did express two deficits: the recall of words from the beginning of the list and the consistency in which they recalled the same word from the prior trial. Interestingly, in comparison with controls, HSAMs recalled more words from List A, which had 5 immediate recall trials. In contrast, HSAM and control subjects recalled a similar number of words from List B, which only had only one immediate recall trial. This disparity hints at an enhanced effect of "active retrieval," in which HSAM participants received a greater benefit than controls when new information was learned through a process of recollecting and restudying the material (Karpicke and Roediger, 2012; Karpicke, 2012). Future studies require a task specifically designed to evaluate this hypothesis. Active retrieval, via the automatic, repeated rehearsal of autobiographical events, may well contribute to the enhanced recall of events by HSAM individuals.

Three Phase Story

For both male HSAM and control subjects retention of the central details in the middle phase of the story (in which emotional events were introduced) was no greater than that of the initial phase. In contrast, controls showed greater recall of peripheral details for emotional middle phase, an effect opposite to the pattern observed by others (Cahill & van Stegeren, 2003; Cahill et al., 2004). Interestingly, both groups reported substantially negative emotional reactions to the story, indicating that they were emotionally engaged. This finding is puzzling, as a memory enhancing effect of emotional engagement has been reported many times (Cahill & McGaugh, 1995; Cahill & van Stegeren, 2003; Cahill et al., 2004; Neilson et al., 2011). The reason(s) for the lack of influence of emotional arousal in increasing memory will require further investigation. These findings provide additional evidence that experiences not directly related to HSAMs' lives are not exceptionally well remembered. Perhaps HSAMs would exhibit emotional enhancement of autobiographical events, but not other information. The results from the Meta-Test further support this conclusion.

Meta-Test

We assessed participants' memory for events that occurred during the cognitive battery testing with our incidental Meta-Test at one-week and one-month delays. The test assessed four events that ranged in degree to which the event related directly to the participants' life: 1) the date, day of the week and time the cognitive battery was administered, 2) the event the participant shared about his/her life, 3) the specific cognitive tests taken and their order, and 4) the details of three stories the researcher shared about herself.

A hallmark of HSAM is a strong and reliable memory for personal life events and the days and dates they occurred (LePort et al., 2012; LePort et al., 2016). The results of the Meta-Test support this finding. They also increase our understanding that HSAM participants do not retain all autobiographical experiences. HSAM participants had superior memory of the day when the cognitive battery was taken, but not the order of the subtests. They also had superior memory of the details of narratives related to their own life events, but not the researcher's life stories. HSAM seems to be relatively specific for events directly tied to their own personal narratives.

HSAM participants' recollection for the order in which cognitive tests took place displayed a positive trend at remote time points, but was not markedly superior to that of controls. Their experience of taking each cognitive test can potentially be viewed as an intermediate case between events that are a major component of the their narrative and events that are less significant. If the memory of the order of the cognitive tasks was not critically important to them, HSAM participants would perhaps be less inclined to think about these particular events and would be even less likely to perseverate on them.

Conclusions

The HSAM participants were superior to controls in performance on only a few of the tests used to assess cognitive performance. While it remains possible that a unique combination of enhanced cognitive processes might be the foundation for HSAM, it is more likely that generally enhanced cognitive processes are not the basis of their ability. What does appear to be essential is the relationship of an experience to their personal narrative. The memories most strongly and consistently recalled by HSAMs were those concerning events they personally experienced.

We suggest the possible hypothesis that HSAMs may habitually recall autobiographical material and reflect on it, resulting in more efficient consolidation and retrieval of this material. We should note that we do not have direct evidence for this hypothesis here or in our existing work as it is not clear how it would be directly observed. This hypothesis is motivated in part by our recent observation that HSAM individuals do not appear to initially encode autobiographical memory in a manner substantially different from that of controls (LePort et al., 2016). Whereas HSAMs' recollections of more remote time-points far exceeded controls', their recollections from the previous week were comparable. In addition, on a measure of obsessive-compulsive behaviors, HSAMs score in the range of patients diagnosed with Obsessive Compulsive Disorder (LePort et al, 2012, LePort et al., 2016). HSAMs may habitually recall and reflect upon their autobiographical narrative, and thus incidentally strengthen their memories of the event and any associated material. Inasmuch as non-autobiographical material might be related to something personal or possibly utilize a story-like narrative, they may apply these techniques for enhanced performance. This hypothesis warrants more directed investigation. From the present results it is clear that HSAM's exceptional autobiographical memory does not result from an equally exceptional ability in any of the cognitive domains assessed in the exploratory study here.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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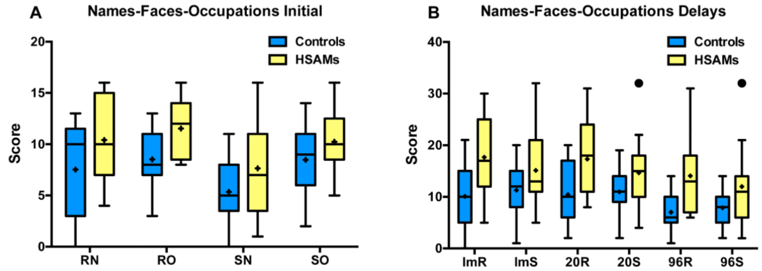

Figure 1. Names-Faces-Occupations Task

Box and whisker plots (Tukey style; outliers in black dots) represent raw scores for each group. A) Recall for the initial test for each encoding task (R = rating, S = scenario) and information type (N = name, O = occupation). B) Recall across each delay (Im = immediate, 20 = 20 minute, 96 = 96 hours) for each encoding task (R = rating, S = scenario). "+" indicates average value

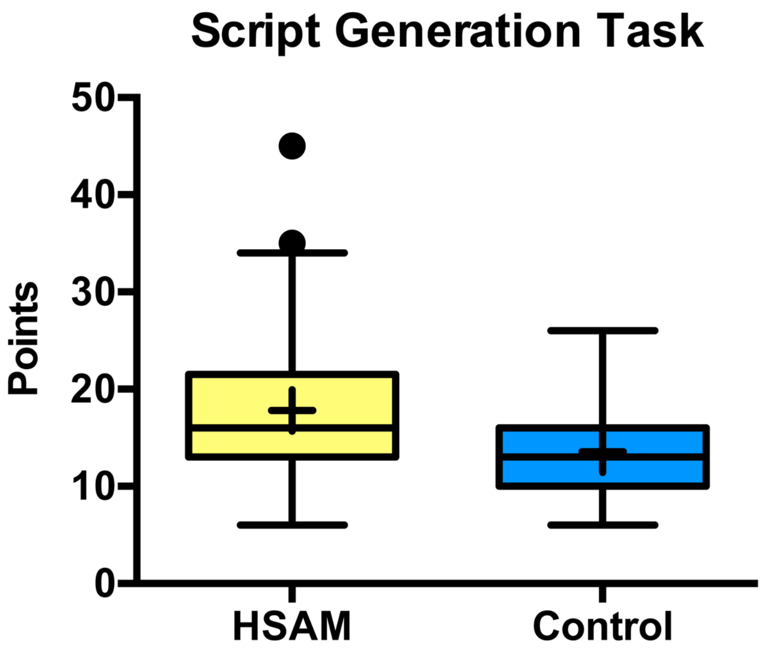

Figure 2. Script Generation

Box and whisker plot (Tukey style; outliers in black dots) demonstrates that the number of raw details was higher for HSAMs than controls.

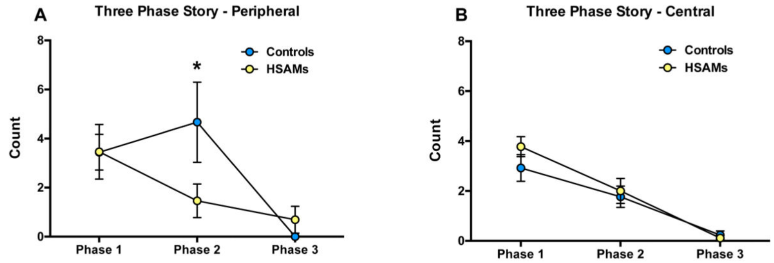

Figure 3. Three Phase Story

Recollection of peripheral details by story phase (1–3) differed per group. A) Controls recalled more peripheral details for Phase 2 (the emotional phase) than HSAMs. B) Recollection of central details for each story phase (1–3) was no different between groups. Values are means ± SEM

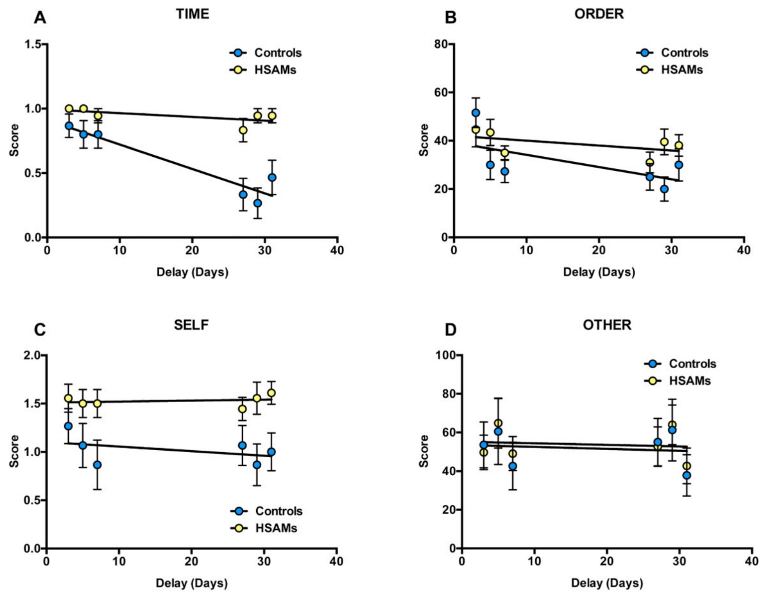

Figure 4. Meta-Test

A) HSAM participants were significantly better at recollecting when (dates/days of week/ times) testing took place over time and at specific time points. B) HSAM participants were similar to controls in their ability to correctly recall the order of the cognitive battery tests taken over time. C) HSAM participants were significantly better than controls at reporting information relating to themselves at all time points. D) HSAM and control participants exhibited a similar ability to recall details of events the researcher experienced. Values are means ± SEM

Table 1

Data from the Stroop Task showing equivalent performance in Controls (N=17) and HSAM (N=19) participants. SD = standard deviation, CI = confidence interval.

	Controls		**HSAMs**	
	Mean	**SD**	**Mean**	**SD**
Color of Dots	71.35	21.31	71.84	16.28
Color/Word Incongruent	124.35	42.03	124.74	27.13
Black Words	51.00	17.57	48.42	9.10
Color/Word Congruent	51.94	19.42	47.21	6.54

Table 2

Performance on the CVLT with reliable differences between HSAM and control performance (correcting for multiple comparisons) in bold. SD = standard deviation, t-stat = t-test value.

	Controls		HSAMs		Difference
	Mean	***SD***	***Mean***	***SD***	***t-stat, p-value***
List A Total Recall	**51.42**	**8.73**	**56.06**	**11.80**	**3.18, p < .01**
Semantic Cluster Ratio	0.9642	1.66	1.826	2.10	0.59, p = .56
Serial Clustering	0.6921	1.22	0.5431	1.19	0.10, p = .92
Percent Primacy Recall	**31.69**	**5.64**	**26.88**	**6.92**	**3.30, p <. 01**
Percent Recency Recall	26.88	7.63	28.9	7.37	1.38, p = .17
Consistency of Item Recall	**79.44**	**9.80**	**65.36**	**5.91**	**9.65, p < .01**
Learning Slope	1.179	0.58	1.475	0.55	0.20, p = .84
List B Recall	5.895	1.83	6.471	1.94	0.39, p = .69
List B vs. List A Trial 1 Recall	−1.211	1.88	−0.8824	1.71	0.22, p = .82
Short Delay Free Recall	10.89	2.61	12.59	2.64	1.16, p = .25
Short Delay v Trial 5 Recall	−0.8947	1.97	0	2.74	0.61, p = .54
Short Delay Cued Recall	12.05	2.42	13.24	2.60	0.81, p = .42
Long Delay Free Recall	11.05	2.87	12.82	2.79	1.22, p = .23
Long Delay Cued Recall	11.84	2.50	13.12	2.68	0.87, p = .38
Recognition Hits	14.74	1.58	15.41	1.03	0.46, p = .54
False Positives	2.053	2.46	1.706	2.19	0.24, p = .81
Free Recall Intrusions	0.0526	0.22	0.1176	0.32	0.44, p = .96
Cued Recall Intrusions	0.6842	0.86	1	1.64	0.22, p = .83
Perseverations	5.737	4.11	4.235	4.76	1.03, p = .30
Discrimination Index	89.61	0.31	90.93	0.11	0.01, p = .99

Table 3

Summary of results across tasks

Task	Results
Face-Name-Occupation	HSAM>CON
Mental Imagery	≈
Visual Patterns	≈
Progressive Silhouettes	≈
Script Generation	HSAM>CON
Emotional 3-Phase Story	CON>HSAM
Stroop	≈
Mnemonic Similarity	≈
California Verbal Learning	≈*
Meta Test	HSAM>CON