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Neuropsychological Investigation of “The Amazing Memory Man”

Jason Brandt and

Department of Psychiatry and Behavioral Sciences and Department of Neurology, The Johns Hopkins University School of Medicine

Arnold Bakker

Department of Psychiatry and Behavioral Sciences, The Johns Hopkins University School of Medicine.

Abstract

Objective: Mnemonists, memory champions, and persons with highly superior autobiographical memory (HSAM) are apparently rare breeds, with no more than a few dozen cases of each described in the neuroscientific literature. This report describes a newly discovered HSAM case who has extraordinary memory for a wider range of material than has heretofore been described.

Method: Subject MM was interviewed about his personal life and administered standard clinical tests of cognition and personality, as well as experimental tasks assessing personal and generic episodic and semantic memory. Finally, he was studied with high resolution structural MRI of the medial temporal lobes, as well as brain connectivity analysis using resting-state functional MRI.

Results: MM’s ability to recall general factual information, historical facts and dates, sports statistics, and popular culture, as well as personal life experiences, is exceptional, even though he performs in only the average range on tests of intellect and new learning ability. Unlike most mnemonists, he denies using any specific mnemonic strategy and, unlike many other HSAM cases, is unable to recall highly specific details of days in his adult life. Structural brain imaging in MM reveals atypical anatomy in his left temporal lobe, and functional neuroimaging suggests greater than usual connectivity of the left hippocampus with premotor, prefrontal and retrosplenial cingulate cortex.

Conclusions: These observations are discussed in the context of previous studies of mnemonists and HSAM cases, some of which implicate hyperconnectivity among components of an expanded memory network in extraordinary memory retrieval.

Keywords

autobiographical memory; superior memory; case report; connectivity analysis

Correspondence concerning this article should be addressed to Jason Brandt, Department of Psychiatry and Behavioral Sciences, The Johns Hopkins Hospital, 600 N. Wolfe Street, Meyer 218, Baltimore, MD 21287-7218. jbrandt@jhmi.edu. Jason Brandt was responsible for the selection, administration, and interpretation of the cognitive tasks in this research. Arnold Bakker was responsible for performing, analyzing, and interpreting the neuroimaging. Both authors participated in the writing of the manuscript.

Throughout the 20th century, there appeared in the psychological literature several detailed descriptions of people with extraordinary memory abilities (Brown & Deffenbacher, 1988; Gordon, Valentine, & Wilding, 1984; Hunter, 1977; Luria, 1968). These “mnemonists”-the most famous of whom was Luria’s case Solomon Shereshevskii, or “S”-displayed phenomenal ability to learn and retain voluminous new information (i.e., episodic memory), usually through some combination of keen attention, eidetic imagery, synesthesia and highly practiced mnemonic strategies (Brown & Deffenbacher, 1988; Luria, 1968). Modern-day mnemonists, such as those who compete in national and international memory championships, appear to train intensively on visuospatial or semantic associate learning strategies (Ericsson & Chase, 1982; Frisch, 2016). These mnemonists are all expert at memorizing random material presented to them (e.g., the order of all 52 cards in a shuffled deck, *pi* to 22,000 decimal places; Ericsson & Chase, 1982; Raz et al., 2009), although there is no indication that they remember ordinary life events better than others do. In addition, neuroimaging studies have generally found that memory experts have quite ordinary brain morphology (Ericsson, 2003; Maguire, Valentine, Wilding, & Kapur, 2003).

Beginning early in the present century, a different type of extraordinary memory has been described. People with so-called “hyperthymesia” (Parker, Cahill, & McGaugh, 2006) have highly superior autobiographical memories (HSAM) in the context of quite average performance on most laboratory and clinical tests of new learning and memory (Ally, Hussey, & Donahue, 2013; LePort et al., 2012; LePort, Stark, McGaugh, & Stark, 2016, 2017; McGaugh & LePort, 2014; Parker et al., 2006; Patihis, 2016; Patihis et al., 2013). Many of these individuals can describe, in great perceptual detail, every day in their adult lives, without obvious rehearsal, practice or reliance on mnemonic devices.

We report here on a newly discovered case of HSAM who has an extraordinary memory for both personally experienced and historical events as well as encyclopedic knowledge. We describe his life, his performance on both standardized psychological tests and memory assessment paradigms, and his brain anatomy and functional connectivity. Finally, we speculate on the neuropsychological mechanisms underlying his unusual talent.

Case MM

Biography

MM is a 63-year-old, right-handed, never-married man who was born and raised in Baltimore, Maryland. He was an only child whose parents divorced when he was young. His father was an artist and his mother worked as a staff member at U.S. embassies around the world before she married. Neither of his parents was known to have unusual memory abilities. MM has a paternal half-sister who he met for the first time in 2012. MM has no contact with extended family.

The subject was raised by his mother and reports an unremarkable early development. He attended Catholic schools and graduated high school in 1970. He attended one year of college before dropping out. He held a number of clerical and customer service positions, the longest of which was 4 years. MM reports being occupationally disabled since age 40 by

major depressive disorder with prominent anxiety. He is treated with sertraline, aripiprazole, and weekly psychotherapy. He has no history of neurological disorder.

Other than one year as a young adult, MM has lived his entire life in Baltimore. He has changed residences very frequently, mostly due to roommate or financial problems, and admits to being homeless for short periods of time. He currently lives alone in a rented apartment and subsists on Social Security payments. He doesn't drive and does not own a computer or use the Internet. MM has six close friends, both male and female, with whom he socializes, but he spends most of his days alone.

On a typical day, MM awakens around 11:00 a.m. or noon. He eats the same breakfast every day. He will then listen to news or talk radio for about three hours before enjoying a light lunch of fruit. In the afternoon, he typically listens to classical music while doing household chores until 5:00 or 6:00 p.m., and then he will go out. He will walk around his neighborhood, shop at local stores, or visit the library. Three evenings a week, he visits local taverns where he will have one beer or a soft drink, converse with the "regulars," strike up conversations with strangers, and compete in trivia contests. He adamantly denies ever drinking excessively. Other evenings, he will return from errands, watch movies on TV, and telephone friends. He eats dinner alone at 10:00 p.m., and will then read before going to sleep around 1:00 or 2:00 a.m. He enjoys Shakespeare and seeks out low-cost, community theater productions. He also follows local collegiate sports teams and attends their games.

Memory Abilities

MM contacted the first author after hearing him on a public radio program concerning memory disorders. He reported an uncanny ability to remember historical facts and dates, sports statistics, and popular culture trivia. He provided copies of local newspaper articles about him dating from the early 1980s, when he was dubbed "the Amazing Memory Man" after pointing out an erroneous date on a major historical monument. A former long-distance runner, MM has a particular interest in athletic events, especially the Olympic Games. He can rattle off the names of athletes, winning times/scores, and medal winners (and losers) with ease. He also can report the historical significance of random dates. For example, given "May 18," he will tell you "that was the birthdate of both Pope John Paul II, in 1920, and Baltimore Oriole [baseball player] Brooks Robinson, in Arkansas, in 1937. It was also that date that the Mt. Saint Helens volcano erupted in 1980."

MM expresses surprise that he remembers little about his life before the age of 7. As a youngster, he had a special interest in American history. He first became aware of his special memory ability at age "29 and 9 months," when he compiled a list of all the historical facts that he could remember. He surprised himself (and others) by how long and detailed it was. Unlike the famous mnemonists "S" (Luria, 1968), Professor Aitken (Hunter, 1977), or "TE" (Gordon et al., 1984), each of whom could describe vividly the strategies or intellectual connections by which he learned and retained immense lists of material, MM is at a loss to explain his unusual memory abilities. Although he enjoys reading about topics of interest, he does not study, take written notes, employ elaborate mnemonics, or attempt to memorize facts. In his words, "they just stick." Unlike autistic persons with savant syndrome, many of whom have exceptional memories (Neumann et al., 2010; O'Connor & Hermelin, 1991;

Treffert, 2009), MM does not have calendrical or other extraordinary calculating skills. He also denies synesthesia, eidetic imagery, or the capacity to reexperience most days of his adult life in perceptual detail (e.g., clothes worn, meals eaten).

When asked how he understands his talent, MM replies “it’s just something I can do.” He feels his memory is, on balance, a “gift,” but he also acknowledges that it is sometimes a handicap:

The sad and horrible things that have happened to me [e.g., the death of his mother, with whom he was very close; a mugging] are always in my mind. ... Whenever the anniversary dates come up, they cause me sadness.

MM reports no diminution of his memory abilities over the years. He stated, “If anything, I’m getting better at it.” He does not perceive any association between his memory and his mood disorder, nor any of the medications he has taken for it. Although some of the psychotherapists he has seen over the 27 years since his first mental health contact have encouraged retrospection and reminiscence, others have not.

Clinical Neuropsychological Findings

With his enthusiastic consent, MM was seen on multiple occasions in 2016 and early 2017 for interviewing and the administration of standardized neuropsychological tests and specialized tasks. Because this single case study is essentially an expanded clinical examination, it was exempted from review by our institutional review board.

Cognitive tests.—MM’s global intellect is solidly average, with better verbal comprehension than perceptual reasoning (see Table 1). His mental processing is very slow, and his constructional praxis (block construction and design copying) is poor. His new learning ability, as measured by the Wechsler Memory Scale and Rey–Osterrieth Complex Figure Test, is solidly average. His memory for auditory–verbal material is better than his memory for visual–spatial material. MM’s prospective memory is normal; he needed no reminders to ask for the return of a borrowed item at the end of the testing session (Bakker, Schretlen, & Brandt, 2002).

Personality and social functioning tests.—MM described himself on the “big five” dimensions of personality by completing the NEO-PI-R (Costa & McCrae, 1995, 2000). He obtained scores within one standard deviation of the mean in all five domains: neuroticism, extraversion, openness, agreeableness and conscientiousness. In contrast to his slowed processing speed on neuropsychological testing and his reserved, solitary lifestyle, he describes himself as a warm and gregarious “go-getter,” with high scores in the facets of competence and achievement striving. On a psychopathology assessment, the Personality Assessment Inventory (Morey, 2007), MM generated an entirely valid profile. There was no indication that he attempted to present himself in an overly positive or negative light. None of the 11 clinical scales was elevated into the clinically significant range. He reported mild, subclinical, physical health concerns and anxiety, but no gross psychopathology.

MM’s social history, quirkiness, obsessional features and pre-occupations have a savant-like character, his normal intellect notwithstanding (O’Connor & Hermelin, 1991; Treffert,

2009). Therefore, we screened for traits associated with high-functioning autism and Asperger's syndrome. His overall score on the Autism Spectrum Questionnaire (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001; Ruzich et al., 2015) is high normal. His only notably elevated trait score is on attention to detail. On the Cambridge Behavior Scale ("Empathy Questionnaire" [EQ]; Baron-Cohen & Wheelwright, 2004), his score is solidly in the normal range. Finally, MM was administered the Friendship Questionnaire (FQ; Baron-Cohen & Wheelwright, 2003) to assess the extent to which close, supportive, peer relationships are important to him. His score was typical for normal men and much higher than that of persons with Asperger's syndrome or high-functioning autism. Based on the AQ and EQ, as well as multiple interviews with MM over many months, the Adult Asperger Assessment (AAA; Baron-Cohen, Wheelwright, Robinson, & Woodbury-Smith, 2005) was completed. MM was far from meeting diagnostic criteria for Asperger's syndrome.

Detailed Memory Assessment

Several tasks exploring memory for the past, including both autobiographical events and generic, world knowledge, were administered to MM:

Autobiographical memory.

Autobiographical Memory Interview (AMI; Kopelman, Wilson, & Baddeley, 1989). The AMI is one of the very few formal, semistandardized methods for assessing a subject's recollection of his or her own life. Under optimal circumstances, a knowledgeable informant would be available to confirm the subject's reports. However, MM assured us that he would say "I don't know" or "I can't remember" if he were unable to retrieve information from his past. However, this was never the case (see Table 2). MM displayed excellent memory for both general semantic information about his life (i.e., facts) and specific, highly detailed, autobiographical incidents (i.e., episodes).

Survey of Autobiographical Memory (SAM; Palombo, Williams, Abdi, & Levine, 2013; Sheldon, Farb, Palombo, & Levine, 2016). This well-validated instrument assesses self-reported memory on trait-like dimensions. Its 26 items measure a person's preference for, and tendency to engage in, four particular types of autobiographical remembering: episodic, semantic, spatial, and projection into the future. MM's standard scores (with means of 100) were Episodic = 123, Semantic = 123, Spatial = 112, and Future remembering = 91. Clearly, MM appreciates that his memory for personally experienced life events and general knowledge are both exceptional, whereas his imaging the future is only average.

Personal Residences Inventory. There is good experimental evidence that residential relocations can serve as an organizing "scaffold" for autobiographical memory (Enz, Pillemer, & Johnson, 2016). In this newly developed task, MM was asked to report the complete address of every location where he resided for at least six months, starting with his current abode. As shown in Figure 1, he could confidently recall the addresses of all 15 of his homes, occasionally forgetting only zip codes. His performance exceeds that of seven of the authors' colleagues.

Generic memory.

Presidents Test (Hamsher & Roberts, 1985; Roberts, Hamsher, Bayless, & Lee, 1990). When most American adults attempt to recall the names of U.S. presidents, either in chronological order or not, they generate the well-known serial position curve (with a “blip” for the 16th president, Abraham Lincoln; Roediger & Crowder, 1976; Roediger & DeSoto, 2014). Most normal subjects, of any generation, can recall the first 3 or 4 presidents and the most recent 7 or 8, but neglect to report those in between. Subject MM was asked to name all the U.S. presidents in reverse order, starting with the then-incumbent (Barack Obama). Not only was he able to recall all 44 presidents, in reverse order and without error, but he often sprinkled his reporting with amusing esoterica about them.

Recognition of Celebrity Faces. MM was shown a grid of 20 color photographs of celebrities from the Northwestern University Famous Faces Test (Gefen et al., 2013) and asked to name them. The persons depicted include entertainers (e.g., Barbra Streisand, Sammy Davis, Jr.), world leaders (e.g., Condoleezza Rice, Pope John Paul II), and other cultural icons (e.g., Muhammad Ali, Princess Diana). MM named all of them with ease, hesitating only on Bill Gates. In addition, he volunteered the date of birth (and, where applicable, the date of death) for most of them. His accuracy was verified with Wikipedia and other Internet resources.

Oscar Test (Brandt & Benedict, 1993). MM was asked to match the title of each year’s Academy Award-winning Best Picture with the year that it won the award. His performance, compared with that of 25 neurologically normal persons averaging 69 years old ($SD = 7$), is shown in Figure 2. His overall superior performance is obvious. For every movie in the nine hemidecades between the early 1940s and the early 1990s, MM’s dating was absolutely perfect. His poor performance for the most recent time period was due largely to a single gross error: he had never heard of the movie “Birdman,” and guessed that it was from 1930.

Date Significance. MM was given 30 random dates (e.g., February 20, November 12), and asked to describe the importance of that date in history. Well-known holidays and other dates of historic significance (e.g., July 4, September 11) were avoided. An informal survey of our colleagues produced zero correct responses. MM was successful for 27 of the 30 dates. He often produced more than one correct historical fact for each date, and he occasionally supplemented these with personal memories. For example, for “July 21,” he paused, his eyes welled up with tears, and he said, “That’s the day my mom died, in 1987.” He then added, “The first major battle of the Civil War, the Battle of Bull Run, was on that date in 1861. Also, Cat Stevens, who wrote my favorite song, ‘Morning Has Broken,’ was born on July 21, 1948.” For one of the 30 dates, he was partially correct. He reported that November 26 was the date in 1963 that Albert DeSalvo, the accused Boston Strangler, murdered Joann Graf, his last victim. Actually, the correct date was November 23, 1963, and Ms. Graf was his next-to-last victim. For the two dates for which he could produce no historically important events, MM produced only personal memories (his grade school and high school graduations).

Fact Retrieval: MM was asked to provide one-word answers to 75 world knowledge questions. The questions were randomly sampled from among the 300 general information items originally compiled and normed by Nelson & Narens (Nelson & Narens, 1980) and more recently updated and renormed by Tauber and colleagues (Tauber, Dunlosky, Rawson, Rhodes, & Sitzman, 2013). MM's accuracy as a function of item difficulty is compared with samples of college undergraduates in Figure 3. Even for questions sampled from among the most difficult items, where the median probability of recall by college students was zero, MM was able to supply the correct answer 63.5% of the time. To provide an indication of his metamemory, MM was asked to rate the confidence of each of his responses (see Figure 4). When he was correct, he was very confident of his responses, regardless of item difficulty. When he stated he was just guessing or was incorrect, his rated confidence was lower overall, and was associated with item difficulty. This suggests intact memory monitoring ability.

Brain Imaging

To explore the cerebral basis for his extraordinary memory, subject MM participated in two neuroimaging sessions. These were performed on a 3-Tesla Phillips scanner located at the F.M. Kirby Center for Brain Imaging at the Kennedy Krieger Institute in Baltimore, Maryland. Scanning was conducted using a 32-channel head coil with higher order shims and SENSE (sensitivity encoding), and included both structural and functional MRI scans. The acquisitions were optimized to evaluate the anatomical features and functional contribution of the structures of the medial temporal lobe (MTL), and included a high-resolution structural scan of hippocampal subregions bilaterally.

Structural imaging.—Structural acquisitions consisted of: 1) a T1-weighted whole brain MP-RAGE scan with 231 oblique slices and a 0.65 mm isotropic resolution, 2) a T2-weighted structural scan consisting of 327 slices, an in-plane resolution of 1×1 mm and a slice thickness of 0.55 mm, and 3) a standard FLAIR MRI scan consisting of 24 slices, an in-plane resolution of 0.45 × 0.45 mm and a slice thickness of 4 mm with a 1 mm gap.

Initial evaluation of the structural scans was performed by a clinical neuroradiologist, who reported “no gross structural abnormality. Multiple punctate white matter FLAIR hyperintense lesions in the periventricular and subcortical regions, likely reflecting small vessel ischemic change.” However, careful review of MM's high-resolution MP-RAGE scan revealed some peculiar features of his cerebral anatomy in two separate locations within the left MTL. First, the collateral sulcus, defining the anterior boundary of the perirhinal cortex, appears much deeper than typically observed (Figure 5A). Significant variation in the depth of the collateral sulcus is not unusual. In fact, a standard atlas of the mesial temporal cortex (Insausti et al., 1998) describes three categories: a “regular” sulcus (10–15 mm deep) was observed in 82% of cases, whereas a “shallow” sulcus (<10 mm deep) was observed in 16% of cases, and a “deep” sulcus (>15 mm deep) was observed in only 2% of cases. MM's collateral sulcus was very deep, at 16.25 mm. In addition, whereas the collateral sulcus is usually fairly narrow, MM's left sulcus appears much wider in the coronal view than is typical. Second, in the left perirhinal and entorhinal cortex, approximately 14 mm posterior to the most anterior boundary of the hippocampus, a circular band of white matter is seen

encircling a ring-like section of gray matter (Figure 5B). As this area typically contains a clearly defined collateral sulcus demarcating the perirhinal and entorhinal banks of the collateral sulcus, it is difficult to determine if this ring-like inclusion represents either entorhinal or perirhinal cortex. These unusual anatomical features were observed only in MM's left temporal lobe; his right medial temporal anatomy was entirely unremarkable and consistent with the typical MTL described in the Insausti atlas.

To evaluate the MTL with volumetric quantification methods, we manually segmented the structures of interest using the high-resolution MP-RAGE scan following previously described methods (Bakker, Kirwan, Miller, & Stark, 2008; Bakker et al., 2012; Kirwan, Jones, Miller, & Stark, 2007). Briefly, using the atlas by Duvernoy (Duvernoy, 2005), hippocampal subfields were defined on eight coronal slices along the anterior-posterior axis of the hippocampus. Representative coronal slices that closest match the atlas were selected and segmented according to the atlas description. The intermediate slices were then segmented in both directions slice-by-slice to provide a smooth transition across slices. The labels for the CA3 region and the dentate gyrus (DG) are combined, as it remains difficult to tease apart these subfields on 3T MRI scans. The entorhinal and perirhinal cortex and the parahippocampal gyrus were segmented according to the delineations described by Insausti (Insausti et al., 1998). (See examples of the manual segmentation in Figure 6A.) The resulting segmentation across the full length of the bilateral MTL was then used to provide a quantification of the volume of these structures. Results from subject MM were compared with that of five age-matched neurologically normal men. Volume of both the left and right hippocampal subregions—including the DG/CA3, CA1 and subiculum—were comparable in subject MM and the control sample (Figure 6B). However, the volume of the temporal polar cortex was considerable larger in MM than in the control sample, particularly on the right. In addition, MM's right perirhinal cortex was lower in volume than average; the left entorhinal cortex was possibly smaller as well. These differences do not appear to be the result of differences in overall brain size, as MM's total intracranial volume was indistinguishable from that of the control group (Figure 6D). Volumes of the left perirhinal cortex, right entorhinal cortex and bilateral parahippocampal cortex were no different between MM and the control sample (Figure 6C).

Functional imaging.—Functional acquisitions consisted of two resting state functional MRI scans with high-resolution echoplanar images collected using an acquisition matrix of 96×96 , a repetition time of 3,000 msec., an echo time of 30 msec., a flip angle of 70° , a SENSE factor of 2, and an isotropic resolution of 1.5 mm with no gap. Images were collected for a total of 10 min. per run during which subject MM was asked to focus on a black plus sign centered on a white background. A seed-style connectivity analysis was conducted using these resting-state fMRI data using SPM8. Following standard methods, volumes were slice-time corrected, realigned, normalized and smoothed. Brain anatomy was segmented into gray matter, white matter and cerebrospinal fluid (CSF). Using the connectivity toolbox (Whitfield-Gabrieli & Nieto-Castanon, 2012), temporal covariates were created using subject-specific white matter and CSF masks and the motion parameters obtained from motion correction. Spatial and temporal filtering was first applied to remove linear trends. Nuisance variables and their first order derivatives, including head motion,

mean global signal, and ventricular and white matter mean signal, were then removed. A left hippocampus seed region of interest (ROI), in MNI coordinate space, was generated among all subjects using the WFU PickAtlas (Maldjian, Laurienti, Kraft, & Burdette, 2003). A seed-to-voxel analysis was then performed using this left hippocampus ROI as the primary seed region. This approach provides an analysis of the correlation between activity in each voxel and the mean time course in the seed region.

Using this approach, functional connectivity measures were generated and compared between subject MM and the sample of five neurologically normal age-matched male control subjects. Clusters of significant functional connectivity were defined using a voxelwise p value of 0.05 and a cluster threshold of 20 or more contiguous voxels. This very liberal criterion for significance was deemed acceptable given the exploratory nature of this case study. The analysis resulted in six areas of increased functional connectivity with the left hippocampus in subject MM compared with control subjects: the left inferior prefrontal cortex (IIPFG: $t = -4.43$, $p < .05$), the left IFC pars opercularis (IIFC: $t = -3.95$, $p < .05$), the left premotor cortex (IPMC: $t = -2.7$, $p < .05$), the left dorsolateral prefrontal cortex (IDLDFC: $t = -2.45$, $p < .05$), the left retrosplenial cingulate cortex (IRCC: $t = -2.41$, $p < .05$) and the right dorsolateral prefrontal cortex (rDLPFC: $t = -2.41$, $p < .05$; see Figure 7). In addition, three areas of decreased functional connectivity with the left hippocampus seed region were observed: the left posterior entorhinal cortex (IPRC: $t = 3.07$, $p < .05$), the left perirhinal cortex (IPRC: $t = 3.47$, $p < .05$), and the right perirhinal cortex (rPRC: $t = 2.86$, $p < .05$).

Discussion

In some ways, MM is similar to other subjects with HSAM (Ally et al., 2013; LePort et al., 2012, 2017; Parker et al., 2006). He has a phenomenal memory for events and dates from his personal past, but only average performance on clinical tests and laboratory tasks of new learning capacity. He does not try to memorize material or employ specific mnemonic strategies. These features make MM and other HSAM subjects different from contestants in national and international memory competitions (Maguire et al., 2003; “U.S.A. Memory Championship,” 2016; “World Memory Championship,” 2016). In addition, MM is not autistic, as he has friendships and relatively broad interests, and he does not possess synesthesia or eidetic imagery. However, MM differs from other HSAM subjects in that his extraordinary memory applies to historical events that he did not personally experience (including those long before his birth) and to general world knowledge. Most HSAM subjects have little interest in thinking about events from dates before they were born (McGaugh & LePort, 2014). Thus, the range of material for which MM has exceptional memory appears to be much broader than that of HSAM subjects previously described (see Table 3). In addition, whereas some HSAM subjects are able to recollect vivid details of most days of their adult lives (including, e.g., weather conditions and meals eaten; Parker et al., 2006; Patihis, 2016), MM does not have this ability.

How are we to understand the phenomenal recall ability of this man of otherwise just average general intellect and lower-than-average mental processing speed? It has been proposed that autobiographical memory is hierarchically organized, from personally relevant

epochs, to general life events, to specific episodes (Conway & Pleydell-Pearce, 2000). MM appears to mentally travel up and down these levels of memory with exceptional ease. He has very strong tendencies to (a) infuse recollections of personally experienced events with descriptions of their historical or cultural context, and (b) insert his own life events into answers to general information questions. This suggests that, for him, the boundaries between facts and episodes, and between the personally experienced and the historical, are especially fluid.

It is tempting to speculate on the relationship between MM's mental health challenges and his extraordinary memory. In fact, many mnemonists and HSAMs suffer from depression or possess obsessional traits (if not full-blown obsessive-compulsive disorder; LePort et al., 2012; McGaugh & LePort, 2014). MM does have longstanding anxiety and depression, but he is receiving treatment and his symptoms are under reasonable control. He is perhaps preoccupied with historical and sports trivia, but he does not have true obsessions or compulsions, and his PAI profile is not indicative of any psychiatric disorder. Some investigators have raised the possibility that excessive anxiety is associated with especially strong memory consolidation, perhaps mediated by high levels of epinephrine (Burke & Mathews, 1992; Patihis, 2016). Nonetheless, any tight linkage between MM's psychiatric condition and his memory abilities remains elusive.

In spite of our many interviews with MM, it remains unclear why he is unable to be gainfully employed. Perhaps his extremely slow processing speed is to blame. Luria's S—who for periods of time had been a journalist, an efficiency expert and vaudeville actor—was also unable to parlay his memory talent into career success. In his case, he was so distracted by images and synesthetic experiences that he was unable to think abstractly or reason conceptually. He ultimately became a stage mnemonist, until this too became impossible, as material from his many performances blended into each other. However, the case of Professor A.C. Aitken, a brilliant mathematician and musician with a phenomenal memory—including for unrelated test stimuli he learned in the psychology lab 27 years earlier—confirms the fact that being a mnemonist does not preclude great intellectual and occupational accomplishment (Hunter, 1977). McGaugh comments that many of the HSAM subjects he has studied lead successful social and professional lives, and include several people in the entertainment industry (McGaugh & LePort, 2014).

It seems natural for neuropsychologists to look to brain structure and function for answers to questions about exceptional cognitive ability. Standard clinical evaluation of MM's brain MRI images revealed no structural abnormalities. In addition, MM's total brain and hippocampal subregion volumes were unremarkable. This is consistent with most of the previous literature. Although Maguire and colleagues (Chadwick, Bonnici, & Maguire, 2014) found that volume of hippocampal subregion CA3 was associated with degree of confusion about past memories in normal subjects, they also found that winners of international memory competitions had undistinguished brains on structural MRI scans (Maguire et al., 2003). However, neuroanatomical differences have often been observed between HSAM subjects and their normal-memory peers. Although the literature is far from unanimous, among the most consistently found differences have been in the uncinate fasciculus, forceps major, and parahippocampal gyrus (LePort et al., 2012). The first two of

these structures are white matter tracks connecting the anterior temporal cortex with the orbital frontal cortex, and the left and right occipital cortices, respectively.

Careful measurement of MM's MTL structures revealed a larger right temporal pole and smaller right perirhinal cortex and left entorhinal cortex compared with men his age with average recall performance. Furthermore, two morphological curiosities were observed: MM's left collateral sulcus is much deeper and wider than what is typically seen and a circular band of white matter surrounding a ring-like section of gray matter is seen on the boundary of his left perirhinal and entorhinal cortices. Although unusual, and confined to structures of the left MTL known to be important for the type of explicit memory in which MM excels, it is impossible to assign functional significance to these observations.

A perhaps more direct approach to assessing a possible neural basis of MM's exceptional memory is the use of connectivity measures derived from functional MRI. This analysis examined patterns of correlated activity across brain regions and time. We discovered nine brain areas that showed altered functional connectivity with the left hippocampus in MM when compared with control subjects. Three areas of reduced functional connectivity were observed, all within the hierarchically organized structures of the MTL. However, the six areas of increased functional connectivity extended to the premotor cortex, frontal cortex and retrosplenial cingulate cortex. Increased correlations between activity in the hippocampus and these areas may suggest greater than ordinary involvement of circuits associated with executive control and modulation of memory function. Specifically, functional connectivity between the hippocampus and the medial prefrontal circuit has been implicated in memory integration, the process by which related memories become interconnected (Schlichting, Mumford, & Preston, 2015; Schlichting & Preston, 2015). The increased functional connectivity observed between the left hippocampus seed and the frontal cortex in subject MM could underlie his remarkable tendency to form connections between unrelated, though coincidental, personal and public events. Furthermore, PET imaging studies have revealed increased metabolism specifically of the right prefrontal cortex and the anterior cingulate in participants who are in the "episodic retrieval mode" (Buckner, Andrews-Hanna, & Schacter, 2008; Philippi, Tranel, Duff, & Rudrauf, 2015; Spreng & Grady, 2010). This may help explain why many previous HSAM subjects have described "uncontrollable remembering" and "thinking about the past all the time" (Parker et al., 2006; Patihis, 2016); in essence being "stuck" in an autobiographical remembering mode.

Overall, our imaging findings in MM are consistent with converging evidence that hyperconnectivity among hubs in an expanded memory network, rather than significant anatomical differences, may underlie extraordinary memory abilities. This is further supported by studies in which damage to this network, which overlaps considerably with the so-called default mode network (Buckner et al., 2008; Spreng & Grady, 2010), was shown to disrupt autobiographical retrieval (Philippi et al., 2015). Of course, our findings of increased functional correlation of hippocampus with frontal and retrosplenial cortical regions must be considered highly tentative. The comparison of a single subject with a small group of control subjects greatly increases the chance of a false-positive finding, especially using unadjusted *p* values as in the present study. However, the areas we found to have either increased or

decreased functional connectivity with the left hippocampus are all well known to play a role in memory function broadly. If the areas of altered connectivity were truly chance observations, a more random distribution of brain areas would be expected. Although the interpretation of clinically normal neuroimaging in a single case may be treacherous, it is likely that extraordinary feats of cognition, such as MM's exceptional memory, are the result of relatively subtle variations in functional connectivity.

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General Scientific Summary

Knowledge about brain systems responsible for human memory has traditionally come from research on subjects with memory disorders caused by localized brain damage. This case study describes a subject with unusually excellent memory for both public and personal facts and events. Brain imaging studies do not reveal any gross abnormalities, but several features of his brain structure and connectivity may help us understand his extraordinary memory capacities.

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Figure 1.

Score on the Personal Residences Inventory for subject MM and mean ($\pm SE$) for 7 physicians and psychologists (the authors' colleagues). For each place where the person lived for 6 months or more, s/he provided the house number, street, city, state, and zip code (1 point for each), and then supplied a confidence rating (1–3) for each item of information. MM has had 15 different addresses (excluding college and temporary housing) over his lifetime. The number of control subjects contributing data decreased after 8 residences. See the online article for the color version of this figure.

Oscar Test Performance in Subject MM

Figure 2.

Performance on *Oscar Test* of subject MM (born in 1952 and tested in 2016) and of 25 neurologically normal control subjects (tested between 1990 and 1993). Scores represent the mean deviation ($\pm SE$) between the year each hemi-decade's movies were said to have won the Best Picture Academy Award and the actual year. Thus, lower scores represent better performance. See the online article for the color version of this figure.

Figure 3.

Accuracy of recall (percent correct) of 25 easy, 26 moderate difficulty, and 24 difficult general knowledge questions for subject MM, compared with median accuracy of college undergraduate students from Tauber et al. (2013). See the online article for the color version of this figure.

Figure 4.

Subject MM's confidence ratings (0 to 100) for general information questions to which he gave correct answers or incorrect answers (including "I don't know"s), as a function of normative item difficulty. See the online article for the color version of this figure.

Figure 5.

Notable features in the anatomy of the left medial temporal lobe in subject MM. *A.* Highlighted section of interest (left) from the coronal view of the left medial temporal lobe (middle) with green line identifying the location in the sagittal view (right) shows deep collateral sulcus with the top of the sulcus almost extending beyond the superior boundary of the left hippocampus. *B.* Highlighted section of interest (left) from the coronal view of the left medial temporal lobe (middle) with green line identifying the location in the sagittal view (right) shows a band of white matter encircling a ring-like section of gray matter spanning both the perirhinal and entorhinal cortices. See the online article for the color version of this figure.

Figure 6 (opposite).

Medial temporal lobe subregion volumes (means $\pm$ SEs) in case MM compared with control subjects. *A*. Coronal section shows the segmentation of medial temporal lobe structures including the entorhinal cortex (ERC), perirhinal cortex (PRC) and the hippocampal subregion structures CA1, CA3/DG/CA2–4 and subiculum in both the left (L) and right (R) medial temporal lobes. *B*. Case MM did not show any marked differences in volume of any of the hippocampal subregions bilaterally compared with control subjects. *C*. MM did show a lower volume of the left entorhinal cortex and particularly the right temporal polar cortex and perirhinal cortex when compared with control subjects. *D*. These differences were observed in the absence of a difference in overall intracranial volume between subject MM and control subjects. See the online article for the color version of this figure.

Figure 7.

Areas of increased and decreased functional connectivity with the left hippocampus in subject MM compared to control subjects. The left inferior prefrontal cortex (lIpFG), left IFC pars opercularis (lIFC), left premotor cortex (IpMC), left retrosplenial cingulate cortex (lRCC), left dorsolateral prefrontal cortex (ldIPFC) and left and right dorsolateral prefrontal cortex (rdIPFC) all had increased functional connectivity with the left hippocampus seed region. The right posterior entorhinal cortex (rERC) and the left and right perirhinal cortex (lPRC and rPRC) all had decreased functional connectivity with the left hippocampus seed. See the online article for the color version of this figure.

Table 1**Neuropsychological Test Findings in Subject MM**

Test and score	Percentile for age
Wechsler Adult Intelligence Scale (4th ed.)	
Similarities SS = 13	84
Vocabulary SS = 11	63
Information SS = 15	95
Block design SS = 8	25
Matrix reasoning SS = 11	63
Visual puzzles SS = 7	16
Digit span SS = 14	91
Arithmetic SS = 11	63
Symbol search SS = 5	05
Coding SS = 6	09
Verbal comprehension index = 116	86
Perceptual reasoning index = 92	30
Working memory index = 114	82
Processing speed index = 76	05
Full scale IQ = 100	50
General ability = 104	61
Wechsler Memory Scale (4th ed.)	
Visual reproduction I = 29/43	25
Visual reproduction II = 9/43	09
Visual reproduction recognition = 4/7	17–25
Visual reproduction copy = 40/43	10–16
Logical memory I = 22/50	37
Logical memory II = 20/50	50
Logical memory recognition = 25/30	51–75
Spatial addition 15/24	84
Verbal paired-associates I = 34/56	63
Verbal paired-associates II = 11/14	75
Verbal paired-associates Recognition = 38/40	26–50
Designs I = 49/120	09
Designs II = 50/120	50
Designs recognition = 13/24	26–50
Symbol span = 13/50	16
Auditory memory index = 102	55
Visual memory index = 85	16
Visual working memory = 100	50
Immediate memory = 89	23
Delayed memory = 96	39

Test and score	Percentile for age
Rey–Osterrieth Complex Figure Test	
Copy = 29/36	02–05
Immediate recall = 15/36	38
Delayed recall = 13/36	21
Recognition trial = 22/24	82
Prospective Memory Test	
0/4 cues needed	88
NEO Personality Inventory—Revised	
Neuroticism T = 56	73
Extraversion T = 59	82
Openness T = 56	73
Agreeableness T = 51	54
Conscientiousness T = 59	82
Personality Assessment Inventory	
Inconsistency T = 37	10
Infrequency T = 51	54
Negative impression management T = 47	38
Positive impression management T = 54	66
Somatic concerns T = 62	88
Anxiety T = 51	54
Anxiety related disorders T = 60	84
Depression T = 51	54
Mania T = 52	58
Paranoia T = 48	42
Schizophrenia T = 42	21
Borderline features T = 47	38
Antisocial features T = 43	24
Alcohol problems T = 41	18
Drug problems T = 42	21
Aggression T = 42	21
Suicidal ideation T = 43	24
Stress T = 57	76
Nonsupport T = 50	50
Treatment rejection T = 53	62
Dominance T = 56	73
Warmth T = 60	84
Autism Spectrum Questionnaire (AQ)	
Deficit scores:	
Social skills = 1/10	
Attention switching = 6/10	
Attention to detail = 8/10	
Communication = 1/10	

Test and score	Percentile for age
Imagination = 5/10	68
Total = 21/50	(higher is more impaired)
Empathy Questionnaire (EQ)	
Total = 40/80	40 (lower is more impaired)
Friendship Questionnaire (FQ)	
Total = 74/135	59 (lower is more impaired)

Note. SS = standard score.

Table 2

Performance of Subject MM on the Autobiographical Memory Interview (Kopelman et al., 1989)

Performance	Personal semantics			Autobiographical incidents		
	Childhood	Early adulthood	Recent life	Childhood	Early adulthood	Recent life
Raw score	19	20.5	21	9	9	9
% of max. score	90.5%	97.6%	100%	100%	100%	100%

Table 3

Varieties of Memory That are Impaired (Down Arrows), Normal (Dashes), or Superior (up Arrows) in the Classic Amnesic Syndrome, Mnemonists, Subjects With Highly Superior Autobiographical Memory (HSAM), and Subject MM, Along With Supporting Tests for Subject MM

	Annesitic syndrome	Mnemonists	HSAM	Subject MM
New learning				
Episodic	↓↓	↑↑↑	—	— Wechsler Memory Scale, Rey–Osterrieth
Procedural	—	—	—	?
Auto-biographic	Facts/Semantics	↓	↑	↑↑
	Incidents/Episodes	↓↓	↑↑↑	AMI Personal Semantics, Personal Residences ↑↑↑ AMI Autobiographical Incidents
Prior memories	World Knowledge/Semantics	—	↑↑	↑↑↑
Generic	Famous People	↓	—	Fact Retrieval, Date Significance ↑↑↑
	Public Events/ Episodes	↓	↑↑	Celebrity Faces, Presidents ↑↑↑
				Oscar Test, Date Significance

Note. Magnitudes of impairments and strengths are authors' estimates based on clinical and neuroscience literature. HSAM = Highly Superior Autobiographical Memory; AMI = Autobiographical Memory Interview.