

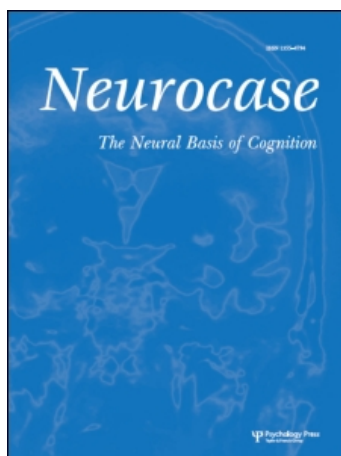
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A calendar savant with episodic memory impairments

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Patients with memory disorders have severely restricted learning and memory. For instance, patients with anterograde amnesia can learn motor procedures and retain some restricted ability to learn new words and factual information. However, such learning is inflexible and frequently inaccessible to conscious awareness. Here we present a case of patient AC596, a 25-year-old male with severe episodic memory impairments, presumably due to anoxia during a preterm birth. In contrast to his poor episodic memory, he exhibits savant-like memory for calendar information that can be flexibly accessed by day, month, and year cues. He also has the ability to recollect the exact date of a wide range of personal experiences over the past 20 years. The patient appears to supplement his generally poor episodic memory by using memorized calendar information as a retrieval cue for autobiographical events. These findings indicate that islands of preserved memory functioning, such as a highly developed semantic memory system, can exist in individuals with severely impaired episodic memory systems. In this particular case, our patient's memory for dates far outstripped that of normal individuals and served as a keen retrieval cue, allowing him to access information that was otherwise unavailable.

Keywords: Memory; Amnesia; Autobiographical memory; Savant; Compensation; Dates, Calendars.

INTRODUCTION

What can one learn in the face of dramatic memory impairments? The learning abilities of patients with anterograde amnesia can be characterized as limited, practice-driven, and inflexible. Procedural skills can be acquired, although learning is usually constrained to the exact parameters of training (Reber, Knowlton, & Squire, 1996). For example, amnesics can learn simple piano pieces (Starr & Phillips, 1970), sequences of arbitrary keystrokes (Nissen & Bullemer, 1987; Reber & Squire, 1998), or how to mirror-write (Gabrieli, Corkin, Mickel, & Growdon, 1993; Milner, 1965) with little or no

generalization. Amnesic patients also show benefits of priming, the increased probability of choosing a stimulus that was encountered earlier (Markowitsch, 2008; Warrington & Weiskrantz, 1974).

Older patients with anterograde amnesia can also acquire some new semantic knowledge (Bayley & Squire, 2002; Bayley, O'Reilly, Curran, & Squire, 2008; Glisky, Schacter, & Tulving, 1986a, 1986b; Hamann & Squire, 1995; Kitchener, Hodges, & McCarthy, 1998; Tulving, Hayman, & MacDonald, 1991; Van der Linden et al., 2001; Verfaellie, Koseff, & Alexander, 2000; Westmacott & Moscovitch, 2001). The degree of semantic learning expressed by these patients is often below that of normal

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individuals and seems to vary with lesion size and degree of amnesia (Bayley & Squire, 2002). An exception to this rule has been provided by reports of semantic learning in patients who acquired their memory disorder early in life – developmental amnesics. These patients can acquire language and semantic memories with modest amounts of repetition and their semantic abilities approach normal levels (Gardiner, Brandt, Baddeley, Vargha-Khadem, & Mishkin, 2008; Vargha-Khadem et al., 1997). Memory disorders in these patients usually proceeded unnoticed until they reached their teens, illustrating the fact that intact acquisition of semantic knowledge can mask abnormal episodic memory (Vargha-Khadem et al., 1997).

Here we present the case of patient AC596, who has extraordinary memory for calendar information in the face of a developmental-based episodic amnesia. Patient AC596 suffered anoxic injury as part of a preterm twin birth. Neuropsychological testing, described below, showed that his excellent calendar memory was accompanied by abnormally poor memory in most, but not all, domains tested. We describe the results of neuropsychological tests of memory, tests of calendar skills, and tests of personal memory for dates.

CASE DESCRIPTION OF PATIENT AC596

Patient history

Patient AC596 is a 25-year-old right-handed male, born prematurely with a fraternal male twin, at 26 weeks gestation, weighing 1 lb, 11 oz. While his brother developed normally, AC596 required considerable respiratory support and only returned home after 7 months, still requiring oxygen. His developmental milestones were delayed. He sat up at 10 months, crawled at 12–13 months, stood at 18 months and walked at 21 months. At 8 years 1 month of age, he was found to have a verbal IQ of 74, performance IQ of 71, and full scale IQ of 71. At 9 years, 2 months, he was retested and found to have a verbal IQ of 76, performance IQ of 55 and full-scale IQ of 64. Based on his expressive single word vocabulary, he was noted to have excellent rote language skills but poor use of language to communicate. At that time, he fulfilled the criteria for Tourette's Syndrome since he had both motor and phonic tics with facial grimacing and arm/fist tensing as well as breathing tics. He

developed vocal tics that could be expressed as grunts. At other times, he was noted to have autistic stereotypes and ritualistic behaviors such as self-directed speech and rocking movements. He did not meet the full diagnostic criteria for autism however. Neurological and psychology testing notes from that time comment that he was preoccupied by cars, car washes, hospitals, and clothing. For example, after a 2-month absence, he was more excited to see his counselor's car than the counselor. He persistently asked to see his counselor's closet and frequently suggested outfits that she might wear. He was noted to have poor social cognition at this age and did not make friends.

Patient AC596 completed high school at age 19 in a special education program run by the state of New Jersey. His performance on the Wechsler Individual Achievement Test (WIAT-II) (Wechsler, 2001) showed that his reading and spelling abilities are at the 1st–4th grade-school levels when he was tested at the age of 23. When first tested he was employed full-time at a local grocery store where he was liked by coworkers. His difficulty negotiating social boundaries is now expressed as 'over-friendliness'. His parents have expressed some concern about his willingness to engage with strangers. They also gave an example of AC596 being oblivious to the impropriety of walking into a private office and sitting down at the computer. Despite these social quirks, patient AC596 does not meet diagnostic criteria for autism.

As an adolescent his obsessive preoccupations shifted first to calendars and more recently to maps. He spends hours in his room looking at calendars and maps. He carries maps of Philadelphia and calendars of the current year with him. His twin has normal intellectual function and does not display any unusual hobbies or savant-like skills.

At the bedside, he was oriented to place and time. His digit span was 6 digits forward and 4 backwards. He was able to learn a 6-word list and remembered 4 words after a delay. His neurological exam was notable for normal cranial nerves, motor and sensory exams. His reflexes, coordination and gait were within normal range.

In the clinic, patient AC596 was friendly, but initially made poor eye contact. He answered questions accurately and in a staccato-like manner. He made frequent throat-clearing sounds, and occasionally rocked in place.

Brain scans

AC596's MRI scans were assessed by a neurologist and appear to be normal. Since preterm birth is a risk factor for neurological and cognitive disabilities (reviewed in (Barrett et al., 2007), and given his delays in accomplishing developmental milestones, it is likely that he has microscopic brain injuries.

Neuropsychological testing

Performance on episodic and working memory was tested with the Wechsler Memory Scale (WMS-III; The Psychological Corporation, San Antonio, TX). The subtests were: a logical memory task consisting of short stories that were read aloud followed by the subject immediately retelling each story; a verbal paired associates task where the subject heard a list of eight word pairs and was then given the first word of each pair and told to give the paired associated with it; a family pictures subtest where the subject was presented with a set of four pictures and asked to remember who was in the scene, where they were positioned, and what they were doing; and a face recognition task in which the subject was presented with a series of faces and told to remember them followed by another set of faces and asked to make an old/new judgment about each face. A similar version of each subtest was administered 25–30 min after the first had been completed. Two subtests that were only tested once included a letter–number sequencing task where the subject had to organize a group of numbers and letters beginning with the numbers in ascending order followed by the letters in alphabetical order. The last subtest administered, the spatial span task, consisted of 10 numbered cubes being presented to the subject with the experimenter tapping a sequence followed by the subject attempting to replicate the same sequence, which progressively increased in length.

Memory for everyday information was tested with the Rivermead Behavioral Memory Test (RBMT) (Wilson, Cockburn, & Baddeley, 1985). The Doors and People Test (Baddeley, Emslie, & Nimmo-Smith, 1994) was used to test his visual and verbal memory in terms of recall and recognition. Long-term visual memory was tested with the Rey–Osterreith Figure-Drawing test (Osterreith, 1944; Rey, 1964). Autobiographical memory was tested with the Autobiographical Memory Interview (AMI; Kopelman, Wilson, & Baddeley, 1989).

Executive functions were tested with the Stroop Color and Word Test (Stroop, 1935) and the Behavioral Assessment of Dysexecutive Syndrome (BADS; Wilson, Alderman, Burgess, Emslie, & Evans, 1996). Quantitative skills were assessed with the Key Math Inventory 3 (Connelly, 2007).

Results: Neuropsychological testing of memory

AC596's performance on standardized memory tests was generally very poor (see Table 1). His performance on the WMS-III, a test frequently used to assess memory in amnesia, was below the 13th percentile in each subtest. His episodic memory and working memory were at or below 0.1% as compared to an age-matched population. His performance on the Rivermead fell in the 'severely impaired range'. His scores on Doors and People were too low to be assessed. Long-term visual memory as assessed by the Rey–Osterreith Figure-Drawing test where he performed below the 1st percentile on the delayed recall subtest. Last, his autobiographical memory was assessed with the AMI. In this test two factors are computed: personal semantic which refers to facts about ones life including former address or names of teachers; and autobiographical incidents which are detailed retellings of events from different time periods. Patient AC596's performance was within the normal range for semantic aspects of autobiographical memory, but 'definitely abnormal' for autobiographical incidents. His normal performance on semantic autobiographical memory was largely due to the ability to recall precise location and calendar information. For instance, he remembered all of his previous addresses (six addresses) and the precise date of nearly every recollected memory. All date information was given spontaneously without prompting. In contrast, episodic autobiographical details such as how he felt or any self-reflective details were impoverished. These findings support the view that his autobiographical memory relies on semantic information.

His poor performance on these tasks cannot be attributed to peculiarities of a particular day or examiner because he was tested by three experimenters on different days, in different locations (his house or the hospital). We also note that he enjoyed being tested and retained a good attitude and mental set about testing. His scores remained in the severely impaired range regardless of testing

TABLE 1
Patient AC596's performance on various standardized memory tests

<i>Test</i>	<i>Subtest</i>	<i>Raw score</i>	<i>Percentile</i>
WMS-III	Aud. immediate	80	9%
	Vis. immediate	57	.2%
	Immediate memory	63	1%
	Aud. delayed	83	13%
	Vis. delayed	53	.1%
	Aud. recognition delayed	55	.1%
	General memory	49	<.1%
	Working memory	53	.1%
Doors and People	Visual memory	0	<.1%
	Verbal memory	9	1%
WIAT-II	Reading comprehension	50	<10%
	Pseudoword decoding	81	<20%
	Spelling	72	<10%
Rivermead Behavioral Memory Test	Standardized profile score	7	<.9%
	Screening score	4	<4.3%
Rey–Osterrieth	Copy	29	<1%
	Delayed recall	6.5	<1%
AMI	Personal semantic	57	Acceptable range
	Autobiographical incidents	11	Definitely abnormal
BADS	Rule shift cards*	1	2 SD less than control
	Action program	2	2 SD less than control
	Key search	6	1 SD less than control
	Temporal judgment	1	1 SD less than control
	Zoo map	12	--normal--
	Interference	8	56 (<i>t</i> -score)*normal
Key Math	Numeration	11	Grade level: 1.6
	Algebra	5	Grade level: 1.3
	Geometry	10	Grade level: 1.2
	Addition + subtraction	9	Grade level: 2.0
	Multiplication + division	0	Grade level: 1.8

On both the WMS-III and the WAIT-II, the standardized mean is 100, with a 15-point standard deviation. Normal performance was obtained on only three subtests: AMI personal semantic, BADs zoo test, and the Stroop.

conditions. Overall, his memory performance was similar to that of patients with anterograde amnesia.

any multiplication or division and only a small portion of the algebra.

Neuropsychological testing of executive functions and math

AC596's performance on standardized tests of executive function was mixed (see Table 1). His performance on the Stroop interference task was normal. His performance on most subtests of the BADs was impaired with the exception of the zoo-map test; here his performance was numerically better than that of controls. These findings indicate that he suffers from significant executive deficits. His good performance on the zoo-map test is testament to his intense interest in maps, which allows him to overcome some of his cognitive deficits.

Testing of math skills showed that he performed similarly to children aged 6–7. He was unable to do

EXPERIMENT 1: CALENDAR TASKS

The goal of Experiment 1 was to characterize the calendar skills of patient AC596. We tested his calendar skills in various ways, using different date cues, in order to gain some insight into the flexibility of his calendar representations. The extant literature on learning in memory disorders such as anterograde amnesia is notable for the many examples of inflexible learning.

Task 1: Day from date

For each trial, a date was presented on a computer monitor using a month/date/year format, for example: April 20, 2008. The task was to respond

which day of the week corresponded to the date given. A 7-alternative forced choice method was used with a single key indicating each day of the week. Responses were unspeeded, but the subject was required to render a response even when he expressed that he was unsure of the correct response. Chance performance corresponds to 14.3%. The dates tested began in 1977 and extended in the future to the year 2035; the year of testing (2007) was not included. There were 120 trials, 10 trials per 4-year bin beginning with 1977–1981.

Task 2: Month of past occurrence

For each trial, a date was presented on a computer screen in a day/date/year format, for example: Wednesday 17th, 2004. The task was to give the month, within the 2002–2008 range, that contained that date. Because the answer to this question can at times be several different months, the subject was told to give the month that occurred latest in that particular year. A 12-alternative forced choice method was used with a single key indicating each month. Chance performance corresponds to 8%. There were 40 trials. Note that this task was administered in August 2008.

Task 3: Year of past occurrence

For each trial, a date was presented on a computer monitor using a day/month/date format, for example: Sunday, January 25th. The task was to use the given information to compute the correct year, within the 2002–2008 range, in which that particular date occurred. A 7-alternative forced choice method was used with the years 2002–2008 serving as response options. Chance performance corresponds to 14.3%. There were 40 trials. This task was administered in August 2008.

Task 4: Month and year of next occurrence

For one-half of the trials, a date was presented using a day/date format, for example: Sunday the 20th. The task was to respond with the correct month of the *next* occurrence of that particular date. For the second half of trials a date was presented using a day/month/date format, for example: Sunday, April 20th. The task was to respond with the correct year of the next occurrence of that combination. Chance performance corresponds to 8% and infinity,

respectively. Dates were presented aloud and the patient responded orally. There were 14 trials. The task was administered in October 2007.

Task 5: Celebrity trivia

Memory for three types of biographical information was tested: memory for celebrity's birthdates, birth mothers, and birthplaces was examined. Memory for each type of information was tested in a blocked format of five trials each. On each trial a face was shown accompanied by the celebrity's name plus one piece of birth information, either their birthdate, birth mother, or birthplace. After 5 trials, there was a short break and each face was shown again but in a new order. The task was to give the name plus the learned birth information. After finishing 5 trials, the next block of trials commenced until three blocks had been completed. These tasks were administered in March 2009.

Analysis of calendar data

Calendar savant skills are very unusual; most individuals do not have the capacity to recollect past or future calendars. As such normal control performance was estimated to be equivalent to chance performance with a standard deviation approaching zero. Any meaningful deviation from this by the patient was taken to be statistically significant.

Equipment

Computerized tests were administered on a Dell laptop computer running ePrime (Psychology Software Tools, Pittsburgh, PA).

Informed consent

Informed consent was attained after reading through the consent form with AC596 and asking him if he understood everything. After acknowledging that he understood, he signed and dated the consent form. We also received parental permission. He signed a Health Insurance Portability and Accountability Act (HIPAA) form stating the intent to keep his personal medical information private, and after going over the entire form with him again he signed and dated giving his consent to participate. This process was repeated for every

session that was conducted with AC596. All experimental protocols were approved by the University of Pennsylvania Internal Review Board.

RESULTS: EXPERIMENT 1

Calendar task 1: Day from date

Data are depicted in Figure 1. Patient AC596's overall accuracy (57.5%) was significantly above chance. However, his performance varied dramatically by decade such that performance was bell-shaped with nearly perfect performance for dates during the 1990s, extending into the 2000s. Performance was worse during the preceding and proceeding decades, although it remained above chance. Smaller bin sizes of 2-year periods revealed that AC596's performance for dates in the upcoming 2 years was also perfect (100%), but that performance for dates further in the future fell sharply. In addition, AC596's performance was superior for past dates (80%) versus future dates (20%). Patient AC596 was born in 1983 and if one hypothesized that his memory for dates was limited to his conscious lifetime, he should have exhibited chance performance for the 1970s and much of the 1980s. However, as can be seen in Figure 1, his performance was still quite good during those time periods.

Patient AC596's errors show that when he did not know what the answer was, he tended to select 'Saturday' as his default response. Out of 51 errors, 39% of the time he reported 'Saturday' as the correct response.

Tasks 2 and 3: Month and year of past occurrence

In task 2, the patient was required to give the last month that a certain day-date-year combination had occurred. His accuracy was 98%, which is significantly above chance performance of 8%. In task 3, patient AC596's accuracy for determining the last year that a certain month-day-date combination occurred was 88%, which is also significantly above chance, 14.3%.

Task 4: Month and year of next occurrence

In these tasks, the patient was required to give the next month or year that a particular date would occur. Patient AC596's was not accustomed to

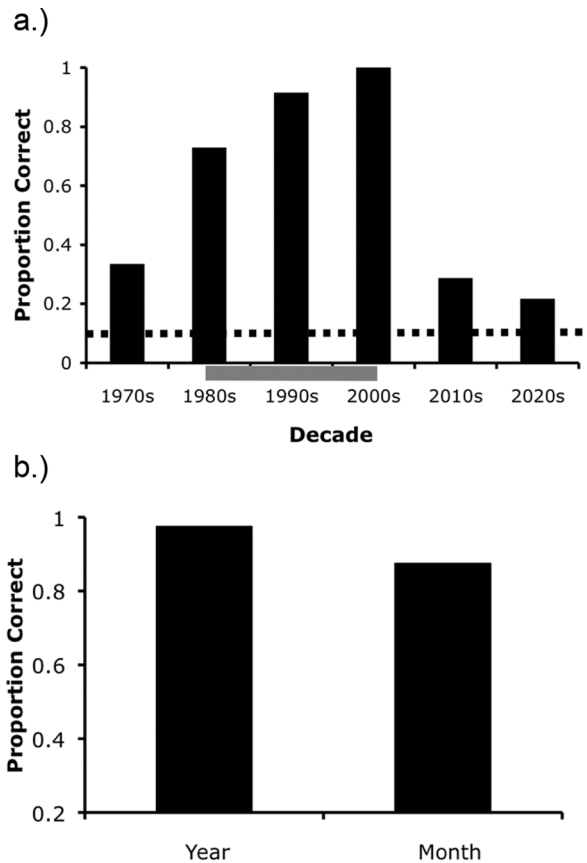


Figure 1. (a) Patient AC596's performance on Experiment 2, Calendar task 1: day from date, binned by decade. The dotted line represents chance performance. The gray bar represents AC596's lifespan overlapping with the epochs of peak performance. (b) Patient AC596's performance on Experiment 3, Calendar tasks 2 and 3: year and month from date. His performance on both tasks is significantly greater than chance, which are, 14.3% for months, and 8% for years.

answering this type of calendar question and stated that the task was somewhat difficult. However, his accuracy on the month task was 86%, significantly above chance performance of 8%. Patient AC596's accuracy for determining the next year that a particular day/month combination would occur was significantly above chance at 29%.

Discussion of calendar tasks

These findings show that patient AC596 is a calendar savant with precise access to internalized calendar information. He can access dates quickly, within approximately 5–10 s. He could flexibly access precise calendar information using either day, month, or year retrieval cues. He was most accurate at providing days when given a date, but still extremely accurate

for providing months and years. His accuracy is higher for dates that occurred within his lifetime, suggesting that he has memorized calendars. We believe that it is unlikely that he computes dates based on implicit or explicit knowledge of repeating calendar cycles because his math skills are very poor (see results of Key Math test). It is more plausible that he has acquired an immense semantic memory of calendar information based on rote memorization. On several occasions we asked AC596 to describe his astounding calendrical knowledge. His response was, 'I just know it'. When probed as to whether he uses techniques such as having a mathematical method or by using important dates as 'anchor' points – he responded with an abrupt, 'No'. However, he would on impulse offer mention of people's birthdays or national/religious holidays when such an event was close to a probed date. These spontaneous references included upcoming dates in the near future (e.g., within the next year), but not for dates farther off in the future.

EXPERIMENT 2: EPISODIC MEMORY FOR DATES AND AUTOBIOGRAPHICAL EVENTS

Neuropsychological testing of patient AC596 showed that he has severely impoverished episodic memory. This was observed across a range of different tasks and stimuli, suggesting that it is a general phenomenon. In contrast, he retains semantic autobiographical knowledge. An example of this is that the autobiographical memories assessed with the AMI did not contain great detail, but they were invariably accompanied by precise date information. The possibility remains that his calendar expertise supports or improves episodic memory when he can use calendar information as a retrieval cue. To explore this question, we presented him with a wide range of questions about personal events, sports events, and family-related events. We developed stimuli by asking his parents to provide information about past family outings, birthdates, and other stimuli such as dated photographs. We reconstructed a timeline of neurology and research testing appointments from consulting physicians and psychologists. Last, we consulted ESPN.com for the dates of past sporting events in the Philadelphia area.

We began by asking him dates of attendance at past Philadelphia Phillies (a major league baseball team) and Eagles (a National Football League team) games. He accurately remembered the dates

and day of the week of attending five Phillies games from a 5-year span, 2003–2008. For the two games in 2003, he remembered the date, the opposing team, and details about which family members had attended and why they had attended. He also noted the time and ticket price of one game. However, he could not remember any other details such as the weather or who won or lost the game. Similar results were found for the three Eagles games. For comparison's sake, we tested the sports memory of one of the authors, D. Drowos, a sports fanatic who is of a similar age, same ethnicity and gender, and who also grew up in the greater Philadelphia area. D. Drowos estimated attending approximately 20 Phillies games over his lifetime (he is currently 23 years old), only two of which he could accurately remember. Both of these occurred in the 3 months prior to testing. For these games, he accurately reported the date, day of week, and who attended the game with him. He remembered the score of one of the game. For games attended in prior years, he had only vague recollections of attending the games (see Figure 2).

Next, we asked patient AC596 about neurology appointments, both clinical and those set up for testing purposes, over the time range of 1991–2008. To test this, we gave him the name of the person he saw and he was asked to give the dates and day of the week that he saw them. He readily supplied the dates of every neurology appointment he has had since the age of 5. He correctly supplied 33 out of 34 dates and days of the week (97% accurate). Appointment dates were given with speed and confidence. He recalled one contextual detail – an instance in which he saw three clinicians on one day, when he was only scheduled to see two. In general however, his recollections were limited to a person linked to a specific day and date.

Patient AC596 was capable at providing dates for almost any personal event we asked him about. For instance, we asked him tell us the dates for

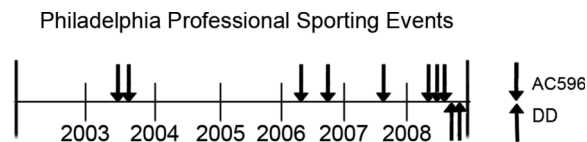


Figure 2. Patient AC596 and D. Drowos' recollection of attendance at past Philadelphia professional sporting events. AC596 was able to recall details of 8 past National Football League and Major League Baseball games dating back to 2003, while compared to D. Drowos who was able to recall only two specific dates that occurred within a 3-month time period prior to testing.

every job he had ever held. He accurately reported the start and end dates for his past four jobs along with his current job, working in the mailroom of a large firm. He reported these dates so quickly and fluently that it was nearly impossible to record his answers.

Photographs appeared to work as a strong memory cue. We went through a family photo album in which we would point at a picture and he would provide dates of the depicted event. He was able to provide more contextual details about such event than when he was only given a verbal cue. For instance, a picture of himself, his mother, and his favorite teacher elicited first the date that the picture was taken, followed by comments that the teacher had taught him math, was really nice, and had given him extra help after school. Other photographs elicited a similar amount of detail.

The tests thus far indicate that his memory for personally significant date information is excellent. To test whether date information for non-personally significant information was similarly elevated we administered a celebrity trivia test where different types of celebrity trivia – their mother's names, their hometowns, or their birthdates – had to be remembered and later recalled (see Figure 3). His performance on this task was poor compared to twelve age-matched control subjects ($M = 24.25$, range = 21–27). He failed to recognize or remember most of the celebrities with the exception of current and former presidents. He performed significantly lower than controls when recalling celebrity names

($M = 0.33$ vs. 0.98 , $z < -10$). His recollection of the birthmothers ($M = 0.20$ vs. 0.82 , $z = -3.89$) and birthplaces ($M = 0.4$ vs. 0.87 , $z = -2.62$) was also significantly lower than that of controls. AC596 performed numerically better than control subjects when birthdate information was tested ($M = 0.60$ vs. 0.43 , $z = 0.49$). This final example indicates that patient AC596's strong semantic knowledge of calendars was sufficiently strong to support new learning.

GENERAL DISCUSSION

We began by asking: What information can be stored in the face of dramatic memory impairments? We investigated this question by performing an in-depth study of patient AC596 who has severely impaired episodic memory skills as assessed by conventional neuropsychological tests. He performed very poorly on the WMS-III, Doors and People, the Rivermead Assessment of Everyday Memory, and the Rey–Osterrieth Figure-Drawing tests. These tests converge on the finding that he has severely impaired working and episodic memory. He also performed poorly on tests of academic achievement and on some, but not all, tests of frontal lobe function. Although his brain scans are unremarkable, it is likely that some combination of microscopic frontal and medial temporal lobe damage, as a result of hypoxia during a preterm birth accounts for this pattern of deficits.

In light of these findings, it is surprising that patient AC596 has accrued such an enormous store of calendar-based information. He is able to flexibly access precise calendar information from day, month, or year retrieval cues. AC596 can be considered a calendar savant based on our testing of his calendar knowledge. Calendar savant skills are overwhelmingly found in the context of retardation or autism, usually the later (reviewed in (Thioux, Stark, Klaiman, & Schultz, 2006). However, we are aware of no reports describing calendar savants with episodic memory impairments. One of the few studies that directly examined memory performance in calendar savants found that they had normal levels of learning and memory on several working memory and long-term memory tasks. One exception to this was found on a test that involved encoding and later recalling a list of years. For this type of information, the calendar savants exhibited

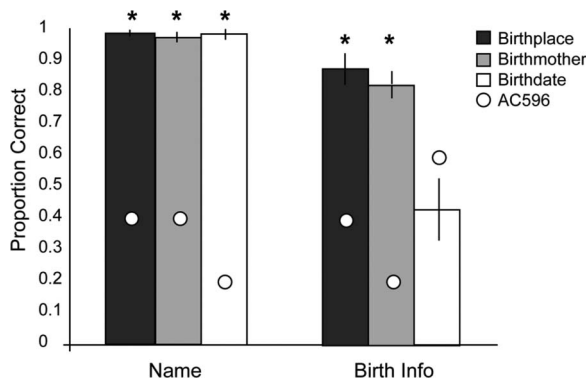


Figure 3. Patient AC596 and 12 matched controls performance on the Celebrity Face Task. The bars show the average performance of control participants, while the white circles indicate the patient's performance. Patient AC596's recall of famous names was significantly lower than controls for all three subtests. His recall of birthplace and birthmother information was also impaired, but he performed numerically better than controls when asked to recall birthdates.

superior memory performance (Heavey, Pring, & Hermelin, 1999). Thus, patient AC596 is quite unusual in that his learning and memory performance is in the amnesic range across nearly every test administered.

Patient AC596's keen memory for calendar information helps him to remember aspects of his past that would otherwise be forgotten. He performed normally on the semantic portion of the AMI because he accurately recalled every home and work address, and the exact dates associated with each memory. All date information was given rapidly, without prompting. In contrast, non-semantic autobiographical details, such as how he or other people felt, were impoverished. This deficit drove his performance on the autobiographical incident measure to fall into the abnormal range.

His performance on the AMI is reflected in his daily life. His father reported that his son spontaneously produces dates of long-ago events accompanied by details of that event. For example, patient AC596 was able to recall the date that his family had eaten dinner at a particular restaurant 10 years earlier – including the name of the limousine driver – even though the family did not regularly discuss that particular evening. Formal testing revealed that he could accurately recall exact dates of sports events, job start and end dates, neurology appointments, and other personal events. His memory for such information extended back to age 5 and all dates were recalled with great speed and ease. Most individuals quickly forget precise temporal information such as time of day, weekday, or day of the month (Janssen, Chessa, & Murre, 2006). Indeed, when we compared AC596's memory for dates of attendance at major sporting events, it outstripped that of a matched control subject who is a self-described sports fanatic (see Figure 2). When given a personal photographic cue, AC596 was able to recall greater amounts of personal information, although dates were always provided first. This is not the first report of superior autobiographical date memory in a calendar savant: patient DG is a calendar savant who has highly accurate memories for past personal events that are linked to dates (Kennedy & Squire, 2007). We note that our patient's autobiographical memory was normal only for semantic aspects of this type of memory; he performed abnormally low on episodic aspects of autobiographical memory.

Mechanism

The literature on calendar savants discusses several possible mechanisms for remembering calendars (Thioux et al., 2006). The first set of explanations can be termed *algorithmic explanations*. These explanations propose that calendar calculation is based on knowledge of the underlying algorithm for calculating dates or use of the cyclical nature of calendars (Hermelin & O'Connor, 1986, 1991; Young & Nettelbeck, 1994). Another explanation, the *anchor date explanation*, is that specific anchor dates within each year are memorized and these dates are used as points to count forward or backward to the target date (Rosen, 1981). Last, it has been suggested that the process is based on rote memorization (Hill, 1975).

AC596 lacks insight into what strategy he uses to calculate dates. He claims his calendrical knowledge is automatic and denies using mathematical algorithms, or associating events with anchoring events such as holidays. The algorithmic explanation does not appear to explain our patient's skills. First, the notable bell curve of AC596's performance shows that his skills are best for years that he experienced, and in all likelihood, calendars that he memorized. It seems unlikely that he has internalized the repeating cycle of calendars. If he had, we would expect performance to be equivalent across all decades, and regardless of probe cue: day, month or year. The variability in AC596's performance, worse for years outside of his experienced lifetime, suggests that he has not done this. Second, if he had used an algorithmic approach, he would require some combination of excellent math skills and working memory. However, his math and working memory skills are very poor. On the Key Math Test he performed similarly to 7-year-old children.

We suspect that patient AC596's calendar skills rely on rote memorization of calendars during his lifespan. Since childhood, his neuropsychological reports have commented on his superior rote memory skills. Family reports indicate that he has an ongoing obsessive interest in calendars. Rote memorization is reliant on practice and repetition, two skills practiced by patient AC596. Rote memorization especially helps encoding and retention of facts, a type of semantic memory. Individuals with hippocampal damage due to early insult acquire normal levels of language and semantic memory (Vargha-Khadem et al., 1997) indicating that the hippocampus may not be necessary for encoding and consolidation

of semantic information, especially if the too-be learned information is repeated (Brandt, Gardiner, Vargha-Khadem, Baddeley, & Mishkin, 2006). The storage and retrieval of semantic information is thought to be closely tied to a normally functioning anterior temporal lobe (reviewed in Markowitsch, 2008). Individuals with frontotemporal dementia show a profile of increasing semantic memory deficits, with relatively preserved episodic memory, as deterioration of the anterior temporal lobes progresses (recently reviewed in Wittenberg et al., 2008).

Patient AC596's superior memory for calendar based information may rely on enhanced attention and hence, encoding, of calendar-based information. His performance on the celebrity trivia test showed that his recall of celebrities' hometowns and mother's names was abnormally low but that he had normal levels of recall for celebrities' birth dates. This finding indicates that he can learn new calendar-based information. His expert-level knowledge of calendars may cause date-based information to be deeply encoded regardless of the encoding environment.

Alternative explanations

An alternative possibility is that the patient's poor performance on the memory tasks is due to his impaired intelligence and poor executive function rather than memory per se. This explanation strikes us as less parsimonious because he exhibited good test taking behavior and was compliant with instructions. Also, his performance was impaired on only some measures of executive function (see Table 1).

Clinical implications

Our results prompt consideration of how these findings might benefit patients with memory disorders. Patient AC596 leads a relatively normal life. He has steady work despite his limited intellectual achievements and episodic memory abilities. Episodic memory impairments usually have a deleterious effect on everyday functioning and are considered to be a strong predictor of poor functional outcome after brain injury since academic, social, and job outcomes are all handicapped (Wilson, 2002). Patient AC596's ability to use dates as a scaffold for recollecting other information masks his otherwise impoverished episodic memory. It allows him to place people and events in an extremely accurate timeline-context. Whether this skill can be

trained is not known, but if it could be instructed, it might improve the daily life of patients with episodic memory impairments.

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