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The structure of savant calendrical knowledge

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PUBLICATION DATA
Accepted for publication 8th January 2012.
Published online 00th Month 2012

ABBREVIATIONS

ASD Autism spectrum disorder

[Abstract]

Aim We aimed to explore the organization of the calendar knowledge base underlying date calculation by assessing the ability of savant calendar calculators to free recall a series of date lists.

Method Four experiments are reported that assessed recall of structural and non-structural features of the calendar in eight savant calendar calculators (seven males; one female; median age 34y 6mo; age range 27–47y), five of whom had a diagnosis on the autism spectrum. The inclusion criterion was a genuine calculation ability rather than an interest in dates.

Results Mean recall was facilitated for material organized according to the structural features of a calendar (leap years, dates falling on the same weekday, dates occurring at 28y intervals) but not for a non-structural calendar feature (Easter Sunday).

Interpretation Distinctions are drawn between two sources of savant calendar-related knowledge, structural and event related. It has been suggested that structural knowledge plays a key role in the acquisition and operation of savant date calculation skills.

What this paper adds

- Structural, as opposed to event-related, knowledge underlies the acquisition and operation of savant calculation.

DOI:

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Developmental Medicine & Child Neurology 2012, **54:** 000−000

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[Text]

Savant calendar calculators can name the day of the week of past or future dates at speed, often in the presence of considerable intellectual impairment.[1] Calculation spans vary, but have been reported to be up to 40 000 years in range.[2] Calendar calculation is often associated with autism spectrum disorder (ASD),[3] but is also seen in those with non-specific learning disabilities[*4] and in individuals who have undergone brain surgery.[5] It is rarely observed in the typically developing population.[6]

There is debate as to how this unusual skill develops. Rote memorization of the calendar, based on extensive practice, is often suggested.[7,8] For some savants, memorization may extend to learning the 14 calendar templates featured in perpetual calendars[9] or the use of anchor/benchmark dates.[10] Indeed, functional magnetic resonance imaging has shown savant calculation to involve brain circuitry that is typically activated by memory retrieval tasks, albeit in a single case study.[11]

The finding that savant calculation spans can exceed the range of perpetual calendars strongly suggests that processes beyond rote memorization must be involved, perhaps in relation to calendar structure.[1] The calendar is characterized by many internal regularities, for example corresponding month structures within the same year and 28- and 400-year cyclical repetitions. The systematic study of response times to date questions has revealed that some savants use these regularities in performing their calculation.[1,12] The suggestion that date calculation does involve at least some calculation processes is consistent with recent functional magnetic resonance imaging data from an individual with ASD who showed similar patterns of parietal activation during both calendar calculation and mental arithmetic.[13] Despite evidence for the use of calendar rules, it is notable that few savants are able to explicitly state these rules and regularities.[14]

Although memory is implicated in savant date calculation, there is little evidence of a *general* memory advantage in savants extending beyond the calendar. Savant date calculators have been found to perform no better than matched typically developing comparison individuals on measures of the short- and long-term retention of words[15] and do not show enhanced performance on psychometric memory scales.[8] However, when long-term recall was tested for calendar items (lists of individual years) and

[*] UK usage for mental retardation.

calculation was not required, savants showed a memory superiority relative to comparison individuals.[15] This suggests that savants encode date information effectively, although this is not due to increased general memory. Rather, the efficient encoding and retrieval of calendar material may relate to how this information is organized and stored in long-term memory.

Savant abilities other than date calculation have been shown to involve stores of organized, domain-specific knowledge. For example, savant musical knowledge reflects the rule-governed structure of tonal music, as evidenced by the superior recall of tonal versus atonal music.[16] Likewise, savant numerical calculation appears to be subserved by a knowledge base that is organized to reflect relationships within the number system.[17] Such findings are consistent with studies of expertise in the typical population, with extensively organized knowledge bases suggested to underlie restricted areas of skill and excellence.[18]

The present study aimed to investigate the organization of knowledge underlying savant calendar calculation. Long-term recall was tested for dates and years presented in two list types: related and unrelated. Related items were linked according to structural features of the calendar (dates falling on the same weekday, experiment 1; leap years, experiment 2; dates occurring at 28-year intervals, experiment 3) and to the flexible occurrence of an annual event (Easter Sunday, experiment 4). Dates and years within unrelated lists served as control items. Enhanced recall for the dates linked according to calendar features would suggest that savant date knowledge is organized to reflect these calendar features. This would be particularly notable given that most of the participants have a diagnosis of ASD. Such individuals often display difficulties in pattern and rule extraction, which is consistent with a preference for local over global processing,[19] with such difficulties evident on recall measures.[20,21]

EXPERIMENT 1

The day of the week is perhaps the most basic unit of calendar structure. Regularities within a given year arise from the fact that every eighth date will fall on the same weekday. By utilizing this regularity, knowledge of the day of the week for just one date in a specific month (e.g. 1 May 1995, Monday) can produce the corresponding weekday for other dates within the same month (e.g. 8, 15, 22, and 29 May, Mondays). This technique may also be applied to calculate the weekdays of other dates (e.g. 2 May 1995, Tuesday) and may be applied across different months (e.g. knowing that 30 June 1995 was a Friday and 1 July was a Saturday, as was 8 July). It is therefore clear how such regularities in the calendar may serve to structure calendar knowledge. As dates falling on the same weekday share a relationship and form a significant regularity within the calendar, these individual dates may be represented in a similar relational format in long-term memory. To test this proposal, experiment 1 required savants to recall lists of dates falling on the same or different weekdays, with superior mean recall predicted for the dates falling on the same weekday.

Method

Participants

Eight savant calendrical calculators (seven males; one female; see Table I for details) were recruited from an existing database of calendar calculators, through advertisements in publications by UK-based charities (e.g. Mencap), and by contacting adult day centres. The key criterion for inclusion in the study was a genuine calculation ability rather than a mere interest in dates. All participants in this research completed an assessment of calculation ability in which nine dates from the twentieth century were presented. Correct responses, on all trials, were typically provided within 5 seconds (maximum=17s; see Table I for mean calculation times). Intellectual ability was assessed using the Peabody Picture Vocabulary Test[22] and Raven's Progressive Matrices;[23] scores on these measures are included in Table I. Five of the participants had received a diagnosis of autism and one participant had social and communication difficulties (see Table I). For these six participants, diagnoses were made in childhood, by trained clinicians, according to DSM criteria.[24] For the purposes of the present study, case notes and diagnostic reports were obtained from parents and support staff in order to verify these diagnoses. Aside from learning disabilities, no comorbidities were reported. Importantly, for all experiments presented in this paper, a diagnosis- and IQ-matched comparison group could not be recruited. This was because of the difficulties experienced by comparison participants in recalling calendar information, even in the form of individual year items, therefore increasing the likelihood of floor performance.[15]

Materials

Four lists of eight dates were presented for recall, each within the calculation ranges of the participants. The related lists (i.e. those that fell on the same weekday) comprised dates that fell on a Monday in 1988 and a Thursday in 1991. The control lists (i.e. those that fell on different weekdays) comprised dates falling on various weekdays in 1989 and 1992. Both the related and control lists included leap years (1988 and 1992) and non-leap, or 'common', years (1989 and 1991) and thus this factor was controlled across list types. Each individual list was printed on a separate piece of card displaying the date (e.g. 24 October 1988) but not the weekday. A card overlay was used with a window that allowed participants to view only one date at a time.

Procedure

Ethical permission for all studies was obtained from Goldsmiths' Research Ethics Committee. Informed consent was sought from participants, and, when relevant, from parents or carers. Lists were presented using an ABBA/BAAB counterbalancing design, which generated eight different orders of list presentation. Before the stimuli were presented, the participants were told that they were to be shown a list of dates that would also be read to them. They were instructed to try to remember the dates as they would be asked to recall as many as possible from the list. Importantly, participants were asked not to calculate the dates. Each date was displayed to the participant for 5 seconds, and then the card overlay was removed and the whole list was displayed for 10 seconds. This was followed by a 1-minute verbal exchange with the researcher. Participants then free recalled the previously presented dates.

Results

All analyses presented in this paper involved repeated-measures analyses of variance (ANOVAs) with the within-group factor of list type followed by linear contrast analyses to compare the recall of each list type. Although the sample size was small and the range of responses limited, ANOVAs were judged as appropriate and sufficiently robust to withstand these limitations.

For experiment 1, a repeated-measures ANOVA revealed a significant main effect of list type (same day leap, different day leap, same day common, or different day common year dates; $F(3, 21)=14.59$; $p<0.001$). Planned linear contrast analyses showed that a significantly greater number of same-day dates (mean 5.88, standard deviation [SD] 1.33) was recalled relative to different-day dates (mean 3.94, SD 1.55; $F(1, 7])=25.58$; $p=0.001$). There was a trend towards a significant effect of year type ($F(1, 7)=3.94$; $p=0.09$) as more dates falling in leap years (mean 5.12, SD 1.36) were recalled than dates falling in common years (mean 4.67, SD 1.39).

Discussion

Savants showed superior mean recall for dates linked according to weekdays when compared with dates that did not share this relationship. Because the related and control lists were comparable for other factors (e.g. the months/years in which the dates fell), the only point of difference between the lists related to weekdays. The resulting superiority in recall is taken to suggest a form of structural mapping; the existing links between these dates in savant memory promoted the encoding and retrieval of these related items. A near-significant trend was observed for dates from leap years being recalled compared with non-leap year dates. Experiment 2 further investigated this trend and the extent to which leap years are linked associatively in savant calendar memory.

EXPERIMENT 2

Leap years are a fundamental aspect of calendar structure. These years contain an extra day, 29 February, and occur every 4 years (with some exceptions). Undoubtedly, savant calendar knowledge must reflect information about leap years, otherwise accurate calculation would not be possible within or across these years. It remains to be explored whether these years are represented in a relational format within savant calendar memory.

Experiment 2 involved the presentation of individual years for recall. Memory for leap years was contrasted with that for odd- and even-numbered common (non-leap) years. The rationale for separating common years is as follows: given that all leap years are even numbered, it is possible that savants apply the odd/even distinction as a short cut to identifying leap years. Although all odd-numbered years can be rejected as potential leap years in the calculation process, an even-numbered year is as likely to be a leap as a common year given the frequency of occurrence in the calendar. This may have implications for recall, with even-numbered common years being as distinctive in savant memory as leap years. Thus, savant memory for individual years may reflect not only the leap versus common status but also further numerical distinctions that are useful in the calculation process.

Method

Participants

Eight savant calendar calculators (seven males; one female) participated in experiment 2 (see Table I for details).

Materials

Three lists of 10 individual years were generated: one related and two control. All years were taken from the twentieth century, so they fell within the calculation spans of each savant. The related list comprised 10 leap years (i.e. 1948, 1956). The second list comprised even-numbered common years, and the third list contained odd-numbered common years. Lists were equivalent in terms of the decades from which years were selected. The order of years was randomized within each list so that items did not fall in chronological order.

Procedure

List presentation order was randomized across participants. For the first list, each year was displayed individually for 3 seconds using a card overlay. The researcher also read out the year. The card overlay was removed and the participants were shown the full list for 10 seconds. Following a 1-minute verbal exchange, the participant free recalled as many of the years as possible. This procedure was repeated for the two further lists.

Results

A repeated-measures ANOVA with the within-group factor of year type (leap, even common, or odd common) revealed there to be a significant effect of year type on recall ($F(2, 14)=8.95$; $p<0.005$). Planned linear contrast analysis revealed that this was due to the superior mean recall of leap years (mean 7.75, SD 1.75) relative to that of common years combined (mean 6.19, SD 1.81; $F(1, 7)=12.76$; $p<0.01$). Further contrast analyses (adopting an alpha value of 0.05/3) revealed that the savants recalled a higher mean number of leap years (mean 7.75, SD 1.75) than odd common years (mean 5.75, SD 1.49; $F(1, 7)=28.00$; $p=0.001$], but not even common years (mean 6.63, SD 2.26; $F(1, 7)=3.76$; $p=0.09$). No difference was observed between the mean recall for even and odd common years ($F(1, 7)=3.94$; $p=0.09$).

Discussion

Leap years were comparatively more memorable than common years only when the means for the two common-year lists were combined. When memory for the three individual lists was compared, mean recall levels were highest for leap years and lowest for odd-numbered common years. Mean recall for even-numbered common years was at an intermediate level, suggesting a continuum of memorability. When recall performance for even-numbered common years was contrasted with that for the other lists, comparisons fell short of statistical significance, probably because of low power. Experiment 3 extended these findings by examining associative links between other structurally identical years – those related by the 28-year rule.

EXPERIMENT 3

The Gregorian calendar contains a 28-year internal repetition: years that are 28 years apart share the same date configuration. As it has been suggested that savant calendar calculators use this rule as part of the calculation process,[12] calendar knowledge should be structured to reflect the relationship between dates that fall at 28-year intervals. To test this, a list of dates sharing the same date and month was presented for recall with each subsequent date falling 28 years later (e.g. 1 July 1914, 1 July 1942, 1 July 1970). Mean recall of this list was compared with that of two lists of control dates that also comprised the same day, date, and month, but at regular intervals of 11 or 17 years (i.e. years that are not structurally identical). Therefore, the dates in the control lists share a pattern of relatedness and fall at regular yearly intervals, but these intervals are of minor calendrical significance. It was predicted that mean recall would be enhanced for items falling at 28-year intervals in comparison with control sequences of dates, which do not conform to a consistent, recursive pattern within the calendar.

Method

Participants

Seven savant calendar calculators (six males; one female) participated in this experiment (with the exception of QF, who was unable to participate owing to illness, see Table I).

Materials

Three lists of eight dates were generated: one related and two control lists. The related list comprised dates that fell at 28-year intervals within the twentieth century. Each half of the list was organized so that the dates fell on the same day and weekday, for example, 6 August 1913, 6 August 1941, 6 August 1969 (all

Wednesdays) and 27 October 1906, 27 October 1934, 27 October 1962 (all Saturdays). The control lists comprised dates falling at 11-year and 17-year intervals. Again, each half of these lists comprised dates that fell on the same weekday. The eight dates within each list were presented as two blocks of four dates, rather than a sequence of eight, to ensure that the dates fell within the calculation spans of all participants. Importantly, the presentation of two blocks of four dates allowed the selection of control lists in which dates fell on the same weekday within blocks, as in the 28-year list, thus eliminating this as a possible confound. The lists were presented to participants individually, with each item displaying the day, month, and year but not the weekday.

Procedure

The order of presentation of the lists was randomized across participants. Participants were shown each date individually for 3 seconds, using a card overlay, followed by an 8-second period in which the whole list was displayed. Participants then free recalled the dates after a 1-minute verbal exchange.

Results

A repeated-measures ANOVA with yearly intervals (28, 11, or 17) as the within-group factor revealed there to be a significant effect of interval on mean recall ($F(2, 12)=21.58$; $p<0.001$]. Planned linear contrast analysis showed a superior mean recall for the 28-year list (mean 6.29, SD 2.21) when compared with the control lists combined ($F(1, 6)=46.50$, $p<0.001$; 11y mean 4.00, SD 2.00; 17y mean 4.14, SD 1.34). There was no significant difference between mean recall for the 11- and 17-year interval lists ($F(1, 6)=0.13$, $p=0.74$).

Discussion

In this third experiment, the mean recall was shown to be superior for the series of dates that map a major recursive pattern with the calendar (28-year repetition) when compared with date sequences of minor calendrical significance (11- and 17-year intervals). This finding is particularly notable given that all the date lists were constructed to control for the weekdays on which dates fell. Thus, even if the participants proceeded to calculate the dates when the lists were presented for encoding, this would not have conferred an advantage for the 28-year dates given that all dates within blocks shared the same weekday. Therefore, the recall superiority observed for the 28-year dates over the control dates must be attributable to the significance of this major repetitive pattern within the calendar.

Experiments 1 to 3 have explored savant memory for material linked according to structural features of the calendar. However, savants are often reported to show outstanding recall for the dates of personal experiences and events (e.g. Olson et al.[25]) – knowledge that is independent of structural patterns within the calendar. Experiment 4 investigated savant memory for one such event, Easter Sunday.

EXPERIMENT 4

The occurrence of Easter Sunday is determined by lunar activity rather than the Gregorian calendar, and can occur on any date between 22 March and 25 April. Therefore, in order to calculate the occurrence of Easter Sunday, it is necessary to be familiar with the phases of the moon – knowledge of the Gregorian calendar alone would be insufficient. In view of the independence of Easter Sunday from the structure of the Gregorian calendar, it is noteworthy that, based on initial interviews, our participants were found to be knowledgeable about the past occurrences of Easter Sundays. Such knowledge was consistent with their ready recall of other event-related information, such as dates of holidays and birthdays.

This experiment investigated whether a sequence of dates, all Easter Sundays, were better recalled than a series of dates that do not share this relationship. A memory advantage for Easter Sunday dates would suggest that savant knowledge is organized to reflect the occurrence of this event within the calendar. In addition, a further manipulation was included to explore the implicit/explicit processing of list relationships. A second list of related stimuli, in the form of another series of Easter Sunday dates, was presented for recall at the end of the task. However, in contrast to experiments 1 to 3, participants were informed of the list relationship before they were required to recall the dates. Thus, should no difference in recall be observed between the first Easter Sunday list and the control dates, this change in procedure would clarify whether making the Easter Sunday link explicitly facilitates recall.

Method

Participants

Eight savant calendar calculators (seven males; one female) participated in this experiment (see Table I for details).

Materials

Three lists of eight dates were generated: two related and one control. The two related lists comprised Easter Sunday dates taken from March and April, spanning the years 1931 to 1992. The control list comprised dates taken from September and October, from the years 1933 to 1990. These months were selected to be comparable with March and April in being adjacent 30- and 31-day months. All control dates fell on a Sunday. The order of dates within each list was randomized so that they were not presented in chronological order.

Procedure

Participants were told that they were to be shown two lists of eight dates that fell on a Sunday (one related list and the control list). The order of list presentation was counterbalanced between participants. Each date was shown individually for 5 seconds, using a card overlay, and read out by the researcher. Participants then viewed the whole list for 10 seconds. After a 1-minute verbal exchange, participants free recalled as many of the dates as possible. Following recall, participants were informed that the dates presented in a previous list were all Easter Sundays and that they would be shown another list of dates that were also Easter Sundays (the second related list). In line with the procedure adopted for the first two lists, participants were presented with this third list and were asked to free recall the dates.

Results

Mean recall scores were analysed using a repeated measures ANOVA with a within-group factor of list type (Easter Sunday/no relationship stated, control list, or Easter Sunday/relationship stated). This revealed a significant main effect of list type ($F(2, 14)=19.74$; $p<0.001$). Planned linear contrast analyses revealed that there was no significant difference between the mean recall of dates from the first Easter Sunday list (mean 4.75, SD 1.39) and the control dates (mean 4.38, SD 1.19; $F(1, 7)=0.66$; $p=0.44$). However, the difference between the mean recall for the first and second Easter Sunday dates (mean 6.75, SD 1.49) was significant ($F(1, 7)=28.00$; $p<0.001$), as was the difference between the mean recall for the control dates and the second Easter Sunday dates ($F(1, 7)=40.11$; $p<0.001$).

Discussion

Mean recall was found to be comparable for the control dates and the Easter Sunday dates for which the relationship between items was not made explicit. As the only difference between lists was the Easter Sunday relationship, this feature does not appear to automatically activate links within the calendar knowledge base to facilitate recall. Given that mean recall was superior when the link between items was verbalized for the participant, it would appear that Easter Sunday dates are related within the savant knowledge base, although the memory processes that operate on such event-related information are unlike those associated with the long-term representation of calendar structure.

GENERAL DISCUSSION

As memory processes are often advocated to explain savant date calculation,[8,9] the present study investigated savant memory for dates in the absence of the calculation process. As it has also been suggested that some savants use calendar regularities in their calculations (e.g. Cowan et al.[1]), memory for dates linked according to calendar rules was compared with the recall of unrelated dates. Results were consistent in revealing that savant memory was superior for lists organized to reflect structural regularities in the calendar. By contrast, the mean recall of dates linked according to the occurrence of Easter Sunday, which is independent of calendar structure, was facilitated only when the list relationship was stated for the participants.

These findings suggest two dissociable sources of savant calendar knowledge: structural and event related. Structural knowledge, as revealed in experiments 1 to 3, reflects relationships and recursive patterns within the calendar. Associative memory may incorporate low-level small-scale mapping between individual dates (e.g. consecutive dates falling on consecutive weekdays) through to more global regularities (e.g. 28-year repetition). For most savants, such knowledge may not be consciously formulated. On further questioning with the present group, the majority of individuals were unable to identify the pattern of list relationships or provide verbal insight into their date calculation methods. In this way, the application of calendar regularities in savant calculation may be similar to the use of grammatical rules; although we may struggle to state the formal rules of grammar, this does not preclude their use.

Based on the findings of experiment 4, it is suggested that savants access a second separable calendar knowledge base relating to the occurrence of events. Savant calendar calculators often show impressive recall for the dates of occasions such as birthdays and excursions, with the present participants readily able to volunteer such information. However, unlike structural knowledge, links within this knowledge store do not appear to be activated automatically to facilitate recall. With regards to the implicit–explicit nature of such knowledge, it is relevant to consider how this information is acquired by savants. The occurrence of events such as birthdays is essentially arbitrary and cannot be predicted solely by knowledge of calendar structure. Knowledge of events can only be acquired explicitly through, for example, access to encyclopaedias and diaries. To continue the analogy with language, the occurrence of events represents the ‘vocabulary’ of the calendar; these events map on to the calendar but are not determined by calendrical structure.

In terms of memory models, both sources of calendar knowledge may be considered as semantic memory, given their factual content. Event-related knowledge is likely to also incorporate autobiographical facts pertaining to the dates of personal experiences. The dissociation of such semantic, factual knowledge about dates from other forms of memory has been noted in a recent neuropsychological case study of a savant calendar calculator.[25] This individual showed flexible access to calendar information in the presence of marked episodic memory impairments.

It is further argued that structural knowledge of the calendar, rather than event-related knowledge, enables the process of savant date calculation. An early interest in dates and the occurrence of events may be precursors of the ability and aid in the elaboration and consolidation of a growing structural knowledge base. However, it is the knowledge of how one date relates to another and the activation of mappings between date representations that constitute the calculation process. In terms of skill acquisition, it is suggested that structural knowledge forms from repeated exposure to day–date pairings derived from many possible sources, including direct engagement with calendars. Through such experience, individuals are exposed to examples of calendar regularities and repetitions. Such information need not be consciously processed; date knowledge may reorganize to reflect structural relationships in the absence of conscious awareness. In this way, rules and regularities emerge from the processing of individual day–date pairings. These embedded regularities then permit generalizations to new dates that were never explicitly processed or deliberately memorized by the savant.[15]

Such a conceptualization of savant date calculation skill is consistent with connectionist modelling of savant date calculation[26] and a more recent model of autistic skill that emphasizes the implicit learning of structures within domains, the generalization of material using similar rules and regularities, and the 'redintegration' of missing elements from recall cues.[27] Further, savant date calculation does not require exceptional or abnormal neural function,[28] nor does it depend on superior intelligence, general memory, or arithmetic skills, although such cognitive factors may help to explain individual differences in calculation skills.[1]

The finding that calendar calculators show superior recall of structurally related (vs unrelated) dates is particularly noteworthy given that the majority of participants had diagnoses of ASD, because individuals with ASD often fail to extract regularities within word lists to facilitate recall (e.g. Tager-Flusberg,[20] Bowler et al.[21]). Indeed, when the current participants were presented with words linked according to semantic and structural/grammatical relationships, recall levels did not exceed those for unrelated word lists (Heavey, personal communication). Thus, as the savant calculators showed a memory advantage only for structurally related dates, rather than for event-related dates and related word lists, this further denotes the differential activation and separable function of the structural calendar knowledge base.

Given the localized processing style associated with ASD, it may appear somewhat paradoxical that savants are able to use calendrical rules and regularities at all. However, rather than being detrimental, autistic cognition is proposed to *facilitate* the acquisition of calendrical calculation skills (also see Happé and Vital[29]). Calendar calculators are not suggested to extract rules directly from the calendar; rather, learning is instance based and derives from exposure to numerous examples of individual day–date pairings. A detail-focused processing style is argued to ‘draw’ individuals with ASD towards these individual elements, with knowledge evolving to represent relations between pairings through subsequent experience and practice (also see Happé and Vital[29]).

Some limitations of the present research should be noted. Findings are based on a sample of only eight individuals, although group studies in excess of three participants are rare in the savant literature. Furthermore, there is heterogeneity within the sample for age at acquisition and initial mode of acquisition of date calculation skills (e.g. whether access to perpetual calendars was reported), speed and range of date calculation, and intellectual and arithmetic skills. Nevertheless, a consistent pattern of memory performance across the sample was observed, which resulted in statistically significant findings with such a small group. Across the experiments, some participants spontaneously announced the relationships between the lists (e.g. that some or all fell on a Monday/Thursday, or occurred at various yearly intervals). This was particularly common in two participants, IR and HD, who have outstanding numerical and arithmetic abilities, respectively. Yet, it is important to note that a differential performance between conditions for the entire group was observed, regardless of the ability to verbalize patterns of relatedness. Theorization relating to the implicit–explicit nature of calendar knowledge must also be taken with caution, given that verbal reports (or lack of) were used to index conscious awareness. This is particularly problematic with the present participants, who demonstrated the characteristic language difficulties of ASD.

ACKNOWLEDGEMENTS

The research presented in this article formed part of the PhD thesis of Dr Lisa Heavey (submitted under the supervision of Professor Linda Pring and the late Professor Beate Hermelin) and includes recent input from Dr Laura Crane. Parts of this research were summarized in Pring[30] and Hermelin.[31] We would like to thank the participants, their families, and their carers for their help with the study, as well as Dr John Reidy for his input and advice on the manuscript.

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Table I. Participant demographics

Savant	Age	Sex	Intellectual ability		Diagnosis	Age calculating began (y)	Calculation range (y)	Mean calculation time for twentieth century dates (s)[a]
			PPVT	RPM				
IR	30	Male	80	102	ASD	7	25 000	3.50
HD	32	Male	79	100	Social and communication difficulties	14	260	2.21
SE	27	Male	64	73	ASD	9	100	5.01
KC	47	Female	59	48	No ASD diagnosis	Not known	100	3.30
KQ	28	Male	44	58	ASD	17	170	5.92
EL	37	Male	66	76	ASD	12	150	1.66
PM	44	Male	55	58	No ASD diagnosis	17	170	5.74
QF	43	Male	78	108	ASD	13/14	160	6.35

[a]Times were determined by presenting nine dates from the twentieth century for calculation. Participants were correct on all trials. ASD, autism spectrum disorder; PPVT, Peabody Picture Vocabulary Test; RPM, Raven's Progressive Matrices.