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Two Day-Date Processing Methods in an Autistic Savant Calendar Calculator

Abstract

Special ability in computing the day of week for given dates was observed in a 24 year-old male (FB) diagnosed with Asperger syndrome. FB performed almost flawlessly (98.2%) both with past and future dates, over a span of forty years. Response latency was slower as temporal remoteness of future dates increased. Within the future timespan, FB's performance was consistent with the active use of calendar regularities. On the contrary, within the past timespan (for which no remoteness effect was seen), his performance was mainly linked to memory retrieval of personal events. The case presented here complements the existent literature on calendar calculators, as, for first time, two distinct day-date processing styles are described in the same individual.

Introduction

Savant "calendar calculators" (CC) are rare individuals who, despite showing limited cognitive skills, are able to report correctly and within seconds the day of the week associated with a specific date (Treffert, 1988; Hermelin & O'Connor, 1986). Since almost no CC is able to describe the mechanisms by which they manage to obtain the correct response, various explanations of this unusual skill have been proposed. It has been noted that the majority of CCs tend to spend a considerable amount of time "studying" calendars. Based on this, it was suggested that their ability might rely on visual imagery of previously-encoded calendars (Howe & Smith, 1988; Kennedy & Squire, 2007), or rote memory of day-date associations (Hill, 1975; Mottron, Lemmens, Gagnon, & Seron, 2006). However, since CC skills often extend to future dates (for which calendars are not normally available), such capacity has also been linked to unconsciously-acquired knowledge of calendrical regularities, e.g., if Jan 1st falls on a Thursday, Feb 1st of the same year will be Sunday. These algorithmic "shortcuts" would help CCs come up with the correct day-date correspondence both for past and future dates (Hermelin & O'Connor, 1986; Norris, 1990; Iavarone, Patruno, Galeone, Chieffi, & Carlomagno, 2007). Although they have been often described as opposed to one another (e.g. Mottron et al., 2006; Snyder 2009; Cowan & Frith, 2009), the "memory-based" and the "calculation-based" hypotheses might be not mutually exclusive. Heavey and colleagues (1999) suggested that savant knowledge of the calendar may originate and develop from the processing of single dates and calendar fragments, for example, a number of individuals with autistic traits show excellent memory for dates of salient occurrences such as holidays, trips, or sport events. Through repeated exposure to sets of day-date pairs, they would gain familiarity with the various regularities within the calendrical structure, and integrate new declarative information within this scaffolding. This 'reprocessing' of encoded knowledge would allow the use of calendar rules, even if these may have never been formally extrapolated through an aware process of mathematical conceptualisation. As a consequence, a mechanism based on the exploitation of rules would enable stored knowledge to be productively used to retrieve the correct day of the week for dates belonging to calendars which have never been directly studied (e.g the far future). Accordingly, this hypothesis predicts that it may be not impossible to observe a CC who responds to day-date queries using a memory-based mechanism for past dates and a calculation-based mechanism for future dates. We hereby describe an autistic savant who shows CC skills using both methods. This pattern suggests that savant day-date calculation might be based on the interplay between memory and algorithmic processing, and this may vary from individual to individual according to the time period explored, and as a function of available cognitive resources.

Case Report

FB, the 3rd son of an Italian middle-class family, is a right-handed male who was 22 years old at the time of the first assessment (Sept 2006). No problems in pregnancy/delivery was reported by his mother. FB achieved the main psychomotor milestones and acquired language within the normal timespan. However, by the age of 4, his parents noticed incipient difficulties in his social behaviour. This was particularly evident in the development of peer relationships, especially at school, where he never attempted to play with other pupils and showed no enjoyment or interest in daily activities. He also exhibited a strong tendency to adhere to obsessive rituals and routines while washing and dressing. By this time, FB also began showing peculiar interests and behavioural patterns. He used to spend most of his time watching television (largely football matches and quiz programmes), of which, by the age of 7-8, he showed a particular ability to memorise details. Similarly, he excelled at memorising events that occurred to himself and his relatives (e.g. birthdays/weddings). Family reports also indicate that he had a concurrent interest in the study of calendars. A few years before his first examination, FB had developed the skill to predict the day of week in which future events would fall. In all likelihood, all main educational targets (i.e., reading, writing, mathematical skills) were partly achieved thanks to the support of his memory abilities, which were described by his teachers as "very good, quite exceptional at times". He attended school regularly, assisted by a teacher specialised in the support of intellectually-disabled students. At the age of 16, his parents decided to withdraw him from school and encouraged him to work in their ice-cream shop, where he became able to carry out routine activities. Before our first assessment, FB had received a diagnosis of "autistic spectrum" or "minor autism" disorder from multiple childhood neuropsychiatrists. Upon request of the national insurance company, he was referred to the Neuropsychological Unit at the [name and city of the institution, obscured for double-blind review purposes], in Sept 2006. Standard neurological examination, EEG and brain CT scan yielded no abnormalities, and FB met DSM IV-TR criteria for Asperger's disorder (American Psychiatric Association, 2000). Although the WAIS-R battery (Wechsler, 1997) indicated borderline intellectual functioning, FB scored within the normal range of performance (Capasso & Miceli, 2001; Barletta-Rodolfi, Gasparini, & Ghidoni, 2011) on the majority of neuropsychological tests administered over the various sessions to better evaluate his cognitive resources. His performance is detailed in Table 1.

Insert Table 1 about here

Testing Phase 1 - Assessment of Calendar Calculation Skills

In Oct 2006, FB consented to have his CC abilities assessed, forewarning us of being unable to respond to dates outside the 1980-2030 window. He was given a structured day-date retrieval task, based on 492 dates homogeneously distributed along the 1986-2026 timeline (stretching out 20 years, equally into past and future). Attention was paid to 1) include equal proportions of each day of the week; 2) represent each month of the 4-decade span; 3) minimise the potential influence of the position of the date within the month, by choosing dates as homogeneously spread as possible throughout the month structure. No fake dates were intentionally used (e.g. 31th Sept). As response to a fake date erroneously included in the testing material (and promptly substituted), FB replied: “It does not exist”. Stimuli were randomly presented as part of two video-recorded testing sessions. Accuracy and response latency were acquired, and FB made six errors. These were uniformly distributed along the timeline and were discarded from the analyses together with the dates of the testing year (2006). Response times were log-transformed to meet the assumption of normality and were then modelled based on a leap year (leap/non-leap)-by-time period (past/future)-by month 2×2×12 *ANOVA*. A sole, strongly significant effect of time period was found ($F_{1, 437} = 574.61$, $p < 0.001$). The overall mean response time was 13.2 s, ranging from 0.50 s (Nov-1990 date) to 164.8 s (May-2026 date). On average, past and future dates took him 3.3 s and 23.7 s, respectively. The presence of a “remoteness” effect was tested separately for past and future. Response times were analysed with linear-regression models as a function of the 240 months sorted along the axis of time. The slope was not significant for the 1986-2005 interval ($r^2 = 0.003, p > 0.05$), whereas it was for the 2007-2026 interval ($r^2 = 0.25$, $p < 0.001$; Fig 1). Overall, these results suggest that responses to past dates did not involve any calculation, as latencies were constant, regardless of how remotely in the past the date was. Vice-versa, the remoteness effect for future dates was suggestive of calculation use. Interestingly, spontaneous recall of autobiographical information emerged during the task in association with many of the past trials (e.g. Oct 4th 1998: “It was Sunday, the day the first episode of The Bold and the Beautiful was broadcast”). Also, the use of calculation procedures for future trials was vaguely mentioned (e.g. 03/04/2016: “If Apr 3rd, 2000 fell on…, Apr 3rd 2016 will be Sunday”). To the request of clarification, similar responses were given: “Every 4 years, I have to move 5 days forward”. Since the visual inspection of the scatterplot depicting FB’s performance over the past interval was suggestive of a potential quadratic trend, we also tested this eventuality. Response times were modelled as a function of a two-block linear regression. Month serial position (1 to 240) was inputted in the first block as in the linear model, whereas the squared serial position was included in the second block. The results indicated a significant quadratic trend ($r^2 = 0.16$), with a significant block-to-block increase in the fit of the model (r^2 *change* = 0.15). This finding suggests that, within FB's "autobiographical window", dates located between 1993 and 1999, i.e., when he started developing and practising memory skills for autobiographical events, are slightly easier than the immediate or the remote past.

Testing Phase 2 - Test of the Priming Effect

The hypothesis of a dual memory-calculation procedure was further explored by investigating the "priming effect" associated with the use of calendrical regularities (Hermelin & O'Connor, 1986). For this purpose, date-pairs were created based on two rules commonly accepted to be used by CCs (Hermelin & O'Connor, 1986; Norris, 1990; Cowan & Frith, 2009): 1) the "month-rule" is based on the knowledge that a date (e.g. 9th May 2001, primer) has a well-determined relationship with other dates having the same day and the same year, but of a different month (e.g. 9th Oct 2001, primed); 2) the "year-rule" is similar to the month-rule, but refers to the computation of the same day-month pair belonging to two different years (e.g. 10th May 2001 and 10th May 2006). Knowledge of these rules was predicted to result in facilitation (and thus, faster responses) for the second date of the pair. Accordingly, 104 date-pairs were extracted from the 1995-2024 period. As task administration took place in 2008, pairs were equally divided (52-52) between past (1995-2008) and future (2009-2024), with 26 pairs of both temporal windows based on one of the aforementioned rules (month-rule: 13; year-rule: 13), and no restrictions applied to the other 26 pairs. Stimuli were homogeneously distributed across the two temporal windows and, with regard to rule pairs, an earlier date was always used to prime a later date. The testing session was, again, videotaped for scoring purposes. Only one mistake was made by FB on these 208 dates. Since the error trial was removed from the analysis, a second pair was randomly removed from the remaining combinations of variable levels (see below). Response latency was then modelled as a function of a within-pair position (primer/primed)-by-time period (past/future)-by-rule presence (present/absent) 2×2×2 *ANOVA*, with both rules merged into a single variable. On average, it took FB 6.5 s to respond. A main effect was found for time period ($F_{1, 192} = 8.82$, $p < 0.0001$, past: 2.2 s, future: 10.8 s). No difference was found between first and second dates of rule-free pairs. Response times were equally fast for past pairs (2.3 s and 1.8 s, respectively), and equally slower for future pairs (11.6 s and 12.2 s, respectively). In addition, a significant three-way interaction was found ($F_{1, 192} = 7.09$, $p < 0.01$; Fig 2). Within the future window, responses to primed dates of rule-pairs were faster than responses to primers (5.3 s and 14.2 s, respectively), but such difference was not visible within the past window. These findings confirm that FB acknowledged and used calendar regularities to compute future day-date associations, and also that differential methods were implemented to obtain the correct response according to the time period of the date. For past dates, he once again spontaneously recalled autobiographical events.

Insert Fig 1 and Fig 2 about here

Testing Phase 3 - The "Easter Test"

To gain further insight on the role of memory in FB's calendrical skills, Easter dates were investigated. These dates are peculiar, because the rule to determine when Easter falls is independent from the pattern of calendar regularities. It is unlikely that CCs who have spent a substantial amount of time in the study of calendars, have also become familiar with the regularities related to Easter dates. Conversely, it is likely that CCs will rely on mnemonic information to come up with the correct date on which a past Easter fell on. Forty-two Easters (1987 to 2029) were selected. At the time of testing (2007) Easters belonging to the 1987-2007 interval were coded as "past" whereas 2008-2029 Easters were coded as "future". Trials were randomised and FB was asked on what date Easter fell/will fall each year (in the form of a “reverse” day-date query), Testing procedures were comparable to those of previous phases. FB responded correctly to 19/21 trials belonging to the past, with two errors committed for 1987 and 1988 Easters. As during testing phases 1-2, personal events were recalled together with the correct response. His score was instead 0/21 for future trials, and he constantly commented that it was impossible for him to respond. These findings corroborate the centrality of a memory-based mechanism for the processing of past dates.

Testing Phase 4 - Investigation of Autobiographical Memories

Findings suggest that FB may have relied on autobiographical information to respond to past date queries. Upon consent, this aspect of his calendar skills was formally tested in a follow-up appointment (May 2008). All trials administered two years before (Phase 1) for which autobiographical information had been recalled (n = 45) were selected and re-administered to FB to verify the consistency of his mnemonic traces. We asked him to provide the correct day of the week and to retrieve all events he could remember having occurred on each of the dates. If no information was spontaneously recalled, an unspecific cue was given (e.g. “Did you do anything particular?”). In addition, we also included 24 new dates associated with international football matches. This was done to explore his mechanisms of autobiographical memory further, given his long-term interest in football. Response latency was, on average, 3 s (100% accuracy). In 35/45 trials, FB recalled autobiographical information consistent with Phase 1 spontaneous retrieval (e.g. “It was the day my aunt got mad at me because I refused to eat my banana”/“It was the day the first Champions League match was played”). Seventeen/35 consistent occurrences were about football matches, whereas the remaining 18 were about daily-life personal experiences or TV events. For the remaining 10 trials, the two sets of responses did not match. The discrepancies were often (5 times) associated with events that had occurred a few days before/after the trial date (e.g. “Four days had passed since my ear surgery"). This was also visible for 9/24 new dates, which day-of-the-week response was initially expected to be cued by recall of a football match. Not only does this longitudinal evidence provide additional support to the use of memory as primary mechanism to respond to past date entries, but it also confirms the genuineness of FB's autobiographical traces.

Discussion

FB is a CC who responded with 98.2% accuracy to 492 day-date correspondences covering a period of 40 years. Such accurate performance on future-date trials relies on knowledge and use of calendrical regularities. This is not new in the literature on CCs (O'Connor & Hermelin, 1986; Cowan, O' Connor & Samella, 2003). However, although our in-house testing procedure might have introduced sources of bias, both response latencies and the explicit recall of personal events clearly indicate that FB also relied on autobiographical memories. In fact, past dates evoked precise memories of personal events, as shown by 77% mnemonic traces consistently reported two years after the first recall. Furthermore, and in a reverse fashion, specific events evoked their appropriate date (85% correct responses for past trials of the Easter Test; see Mottron et al., (2006) on the role of memory in the ability to answer "reverse" day-date questions). In this framework, FB's autobiographical memory resembles that of AC596, a 25 year-old male with severe episodic-memory impairments described by Olson, Berryhill, Drowos, Brown and Chatterjee (2010). AC596 was reported to have memorised calendar information over a period of 20 years and used this as a retrieval cue for autobiographical events. Additionally, as with FB who claimed that he could not respond on the date of Easter 1987 and 1988 since "at that time he was too young", AC596's knowledge of past dates was constrained to a period of personal "aware experience" (see also patient AJ, described by Parker, Cahill and McGaugh, (2006)). Despite these computational similarities, an important question still has to be answered concerning the relationship between the two day-date processing mechanisms shown by FB. Should these be considered two separate skills developed across two possibly unrelated (past/future) domains (e.g, see the multiply-talented GW, described by Wallace, Happè and Giedd (2009), who exhibited savant CC and art skills)? Or, alternatively, are these in some way the result of FB's obsessive overexposure to calendrical rules, productively transferred to the organisation of autobiographical memories, and generalised to day-date calculation algorithms? Unfortunately, the experimental evidence collected on FB is not sufficient to give appropriate answers. However, in the attempt of drawing a satisfactory, yet parsimonious explanation of FB's pattern of performance, we propose that the mastery of calendar regularities provided him with a structured framework for encoding and retrieving personal information of the past, and for relying on these mnemonic traces as preferential route to access to the correct date-entry day of the week. In parallel, his cognitive competence allowed him to practise day-date regularities and exploit them for cueing future recurrences and commitments. If this were true, such "creative" use of calendar knowledge would question the generalisability of models for autistic cognition which suggest that CC savant skills simply stem from stereotyped behaviours/interests.

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Table 1. FB's cognitive performance

Neuropsychological Test	F.B.'s Performance	Cut-Off of Normality
WAIS-R - Total	78	≤ 80
WAIS-R - Verbal Section	81	≤ 80
Information	7	
Digit Span	11	
Vocabulary	5	
Arithmetic	6	
Comprehension	5	
Similarities	7	
WAIS-R - Performance Section	77	≤ 80
Picture Completion	4	
Picture Arrangement	11	
Block Design	10	
Object Assembly	6	
Digit Symbol	4	
Other Cognitive Tests		
15 Words or Rey - Immediate Recall	51.9	≤ 28.53
15 Words or Rey - Delayed Recall	8.2	≤ 4.69
Prose Memory Test	14	≤ 7.5
Token Test	30.75	≤ 26.5
Letter Fluency Test	22.4	≤ 17.35
Phrase Construction Test	22.5	≤ 8.72
Raven's Progressive Matrices 47	32.8	≤ 18.96
Visual Discrimination	32	≤ 21
Copy Design	11.6	≤ 7.18
Copy with Landmarks	69.2	≤ 61.85
Digit Cancellation Test	26.25	≤ 30
Trail Making Test B	290	≥ 283
Stroop Test - Time Interference	38.5	≥ 36.92
Stroop Test - Error Interference	6.5	≥ 4.24
E.N.P.A. (calculation/number-processing subtests)		
Repetition	9.8	≤ 8.8
Reading	8.3	≤ 7.6
Writing	6.7	≤ 6.3
Word-Number Transcoding	5.2	≤ 4.2
Additions	2.8	≤ 2.2
Subtractions	3	≤ 1
Multiplications	2.4	≤ 1.4

Raw performance is indicated in association with the WAIS-R subtests, whereas the other scores characterise FB’s cognitive performance after correction for age, education levels, and gender.

Figure Captions

Fig 1

Response latency to past and future trials for which FB reported the correct day of the week

Raw response times are depicted at the top (1A). Log-transformed latencies are schematised at the bottom (1B). The regression line fitted to each of the temporal windows is illustrated as a continuous line. The quadratic trend fitted to the past temporal window is illustrated with a dotted line.

Fig 2

Priming effect in FB's calendrical calculation

Mean values of response latency as a function of the main effects of and interaction between within-pair position (primer/primed), time period (past/future) and rule presence (present/absent).