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# A date to remember: the nature of memory in savant calendrical calculators

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## ABSTRACT

**Background.** Savant calendar calculators can supply with speed the day of the week of a given date. Although memory is suggested to be an important component of this unusual ability, memory function has never been systematically investigated in these skilled yet learning impaired individuals.

**Methods.** Eight savant calendrical calculators, most of whom had autism, were compared with eight verbal IQ, age and diagnosis matched controls on digit and word span tests and measures of long-term memory for words and calendrical information (individual years). In an analogue to the 'generation effect', the savants' memory for dates was also compared following calculation and study/read tasks.

**Results.** The savants did not differ from controls on measures of general short- and long-term memory. They did, however, show a clear recall superiority for the long-term retention of calendrical material. They also remembered calculated dates better than those that were only studied.

**Conclusions.** A general mnemonic advantage cannot explain savant date calculation skills. Rather, through exposure to date information, the savants are suggested to develop a structured calendar-related knowledge base with the process of calculation utilizing the interrelations within this knowledge store. The cognitive processing style characteristic of autism may also play a role in the acquisition of this savant ability.

## GENERAL INTRODUCTION

The phenomenon of the idiot-savant offers a unique opportunity to investigate the presence of isolated skills against a background of general cognitive impairment. Such savant abilities include artistic talent (e.g. Mottron & Belleville, 1993, 1995; Pring *et al*. 1995), musical ability (e.g. Sloboda *et al*. 1985; Miller, 1989; Young & Nettelbeck, 1995), numerical calculation skills (e.g. Anderson *et al*. 1998) and mnemonic skills (O'Connor & Hermelin, 1989). Perhaps the most unusual ability, however, is that of calendrical calculation, which involves the generation of the weekday of a given date within seconds. Savant calculation spans are reported to be as limited as 5 years (Rubin & Monaghan, 1965) and as extensive as 40000 years (Horwitz *et al*. 1969).

Various explanations of this peculiar skill have been considered. While published formulas and algorithms exist for calculating dates and can be found in encyclopaedias and almanacs, it is widely accepted that savant calendrical calculation is unlikely to be based on such detailed and complex preformulated methods (O'Connor & Hermelin, 1984; Howe, 1989; Spitz, 1994, 1995). Not only is it implausible that learning disabled individuals have access to the relevant publications, more importantly, the mastery of such formulas requires a level of reading, comprehension, memory and numerical ability clearly beyond that of most savants. However, perpetual calendars, which reflect the relation-

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ships between dates and the structure of the calendar, may represent a more feasible published source from which savants gain their knowledge. It has been suggested that savant date calculation may be based on visual imagery of the calendar (Roberts, 1945; Howe & Smith, 1988) although Rubin & Monaghan's (1965) study of a congenitally blind calendrical calculator, with no access to a braille calendar, appears to rule out visual imagery as a universal explanation. Rosen (1981) proposed a strategy for savant date calculation that involves the memorization of specific anchor dates within a year. These dates can then be used to 'key off', to count forwards and backwards from the anchor date to reach the target date, a process that also requires knowledge of the systematic changes within the calendar. In an earlier study, however, Hill (1975) rejected this explanation of savant date calculation and concluded that the skill is based on a process of rote memorization, similar in nature to the 'memory of adolescents who learn statistical information pertaining to their favourite sports' (Hill, 1975, p. 560). Similarly, the outstanding date calculation skills of the famous twins George and Charles (Sacks, 1985) were explained in terms of the rote memorization of the calendar based on endless practice (Horwitz *et al.* 1965, 1969).

More recent studies of savant date calculation have emphasized the use of calendrical rules and regularities as part of the calculation process. In an analysis of the date calculation speeds of eight savants, Hermelin & O'Connor (1986) noted the use of the 'corresponding monthly rule'; that certain month pairs share the same date structure. The savants were also observed to utilize the 28 yearly repetition intrinsic to the Gregorian calendar, a finding supported by Ho *et al.* (1991) and by O'Connor & Hermelin's (1992) study of two 10-year-old savant calendrical calculators. Similarly, Young & Nettelbeck (1994) noted a facilitation in calculation speed for dates falling in years with an identical structure when compared to dates from years with different calendrical configurations. Thus, it would appear that savants utilize their knowledge of calendar structure as part of the date calculation process. In addition, some rare cases of calendrical skills are also accompanied by outstanding numerical ability (Sacks, 1985; Heavey *et al.* 1998*a*).

It is probable that savant date calculation depends on a combination of these different explanations and may vary from individual to individual, depending on initial experience with the calendar and the ability level of the savant. For example, small calculation spans may be achieved on the basis of practice and rote learning. However, savants with larger calculation spans appear to make efficient use of calendrical regularities, particularly the more intelligent calculators (Hermelin & O'Connor, 1986). It is also conceivable that access to a perpetual calendar may give rise to a strategy involving visual imagery. Regardless of this heterogeneity, it is possible to identify an aspect of cognitive functioning that is central to all of the suggested explanations: the process of savant calendar calculation is subserved by memory, by the retention of calendar information in long-term memory. In view of the fact that memory is implicated in all of the reviewed explanations, it is surprising that there has been no direct systematic investigation of long-term memory function in the savant calendrical calculator. The present study thus seeks to address this issue; specifically by exploring the encoding, storage and retrieval processes which underlie savant date calculation. Furthermore, as all previous studies of calendar savants have examined the individual's knowledge of dates by requiring them to calculate the items, such a study of memory ability, as distinct from calculation, provides an alternative, more exhaustive means by which to investigate savant date knowledge.

The present paper outlines three studies concerned with different aspects of savant memory performance. Before proceeding to an investigation of long-term memory, Experiment 1 examined whether savant calendrical calculators and matched controls differ in terms of basic short-term memory capacity and patterns of immediate recall. The groups were compared on span measures involving both digits (intrinsic to the construction and representation of the calendar) and words (unrelated to the calendar). Relevant to this first study is Spitz & LaFontaine's (1973) finding of a savant advantage, in relation to mentally handicapped controls, for the forward recall of digits; a finding which suggests that superior short-term memory function may be one component of savant ability. Experiment 2 compared the long-term recall of savant calculators and control subjects for both calendrical and general material; investigating specifically whether the savants' extensive knowledge of the calendar would facilitate the recall of calendrical items. Experiment 3 explored the effect of differing encoding conditions on the savants' memory for date information. It was of interest whether the calculation of dates would lead to superior retention when compared to the reading of dates, suggesting differential activation of the savants' calendar knowledge base. It is notable that the first two experiments compared the performance of the calendar savants with an appropriate IQ and diagnosis matched control group; a methodological design unique in the savant date calculation literature and possible only because memory rather than calculation was under investigation.

# Experiment 1

## INTRODUCTION

Savant calendar calculators are able to answer with ease such questions as 'What day of the week was the 17th July 1964?' when presented aurally. At the very least, this feat necessitates the retention of the target date in a temporary store until the answer, in the form of a weekday, can be generated. The use of calendrical rules as part of the calculation process may further require the mental manipulation of information held in a short-term store; for example, counting forwards or backwards in multiples of 28 in accordance with the 28-year repetition (Hermelin & O'Connor, 1986). Calendar calculation may thus involve both the transient storage of calendar items and the active processing of date information (Dorman, 1991).

Most accounts of savant short-term memory (STM) derive from the use of span tests. Such measures, which require the immediate repetition of a string of items in their exact sequence of presentation, represent a standard index of short-term storage capacity and are appropriate for use with a learning disabled sample. Superior STM function was noted in a group of eight savants with various isolated abilities when compared with 25 mentally handicapped controls (Spitz & LaFontaine, 1973). The mean forward digit span of the savants fell within the $7 \pm 2$ range, like that of eight intellectually normal controls also included in this study. Digit spans falling within or exceeding this range have also been reported in single case studies of savant date calculation (Hill, 1975; Ho *et al*. 1991).

The present study of STM investigates whether a group of savants skilled specifically for calendar calculation differ from verbal IQ, age and diagnosis matched controls on measures of immediate recall. In addition to measuring the forward recall of digits, backward digit spans were recorded. It is possible that the cognitive operations performed on a series of digits in order to retain their exact sequence followed by their mental reversal may capture an element of the active manipulation of numerical sequences that occurs during the use of calendrical regularities. Finally, in addition to investigating the short-term recall of numerical information, immediate memory for non-numerical verbal items was tested in the form of forward and backward word span measures. These tasks were included to investigate possible differences in the immediate recall of numbers, which play an important role in the construction of the calendar and the denotation of date information, and common nouns, none of which was relevant to the calendar or the phrasing of date questions. Not only would a savant STM superiority inform the subsequent long-term memory (LTM) studies of both calendrical and non-calendrical material, such a finding would have implications for an understanding of the underlying cognitive differences between savants and controls, shedding light on the factors that predispose individuals to develop this unusual skill.

## METHOD

### Participants

Eight calendar calculators took part in the present study. Seven of these individuals have received a reliable diagnosis of autism with the remaining subject regarded as having non-specific learning difficulties. The mean chronological age of the savants was 28·7 years (S.D. = 9·0). The mean verbal IQ of the group, as measured on the Peabody Picture Vocabulary

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Test, was 64·9 (S.D. = 13·2). All subjects were able to calendar calculate over a minimum span of 100 years encompassing the present century.

Eight control subjects were individually matched to the savants on the basis of diagnosis, chronological age and verbal IQ. These individuals were selected from a National Autistic Society (NAS) day centre and three NAS residential homes. The remaining subject, with more general learning difficulties, was contacted through a local authority adult training centre. The mean chronological age of the control group was 29·1 years (S.D. = 9·2), which did not differ significantly from that of the savant group ($t(14) = 0{\cdot}07$, NS). The mean verbal IQ of the control group, as obtained on the Peabody Picture Vocabulary Test, was 66·8 (S.D. = 12·7), which again did not differ significantly from that of the savants ($t(14) = 0{\cdot}29$, NS).

Although not individually matched in terms of arithmetical ability, prior testing (Heavey, 1997) revealed the two groups to have comparable levels of performance on the WISC-III (Wechsler, 1992) arithmetic subtest. The mean number of items correctly solved by the savants and controls was 10·8 (S.D. = 5·6) and 9·4 (S.D. = 5·4) respectively ($t(14) = 0{\cdot}50$, NS). Given the relatively basic arithmetical skills of each group as a whole, the WISC-III was selected rather than the age-appropriate WAIS – R (Wechsler, 1981), which was expected to concentrate scores in a restricted, lower range.

Prior to the testing phase, the control subjects were assessed to show at least a minimal level of knowledge of the calendar. For example, they could name the days of the week in order and they could also select, from a list of candidate years, the current year of testing. None of the controls was able to calendar calculate, however, neither were they reported by parents and staff as taking a marked interest in birthdays or in other calendar related events.

### Materials

*Digits*

The digit span subtest from the WAIS-R (Wechsler, 1981) was used. This involves two parts; digits forward and digits backward. In the forward test, the subject is given a series of number strings, composed of the digits 1 to 9. The first strings comprise three digits and gradually increase in length until they consist of nine digits. Two trials are presented for each item length. The items involved in the digits backward test differ only in the length of the initial and final trials. The first item presented is two digits in length and the final item is eight digits long.

*Words*

The word span tests were constructed by matching a high frequency, one syllable word (Thorndike & Lorge, 1968) to each of the digits 1 to 9. Each of the words began with a different letter and care was taken to select phonologically dissimilar words in an attempt to reflect the lack of phonological resemblance between the digit labels 1 to 9. The sequences of numbers used in the digit span test were then reconstructed using the corresponding words. For example, the sequence '5–8–2' became 'face–hat–dog'.

### Procedure

The order of presentation of the digit and word span tests was alternated between the savants together with their respective controls. Following from the WAIS-R presentation format, the forward measure always preceded the backward measure within the separate word and digit tests. In the forward condition, subjects were informed that the experimenter would read out some numbers/words and that they should listen very carefully. When the experimenter had finished, they should repeat exactly what the experimenter had just said. In the backward condition, the subjects were informed that the experimenter would read out some numbers/words, but this time they should say the items in the reverse order. Several examples were given of how to reverse both digit and word sequences.

In line with the standard presentation format, the items were read out at the rate of one per second. Both of the trials on each item length were administered and the test was discontinued following the subject's failure to repeat the item string correctly on both trials of the same length.

## RESULTS

Subjects' digit and word spans were derived from the length of the last item-string correctly recalled. The mean span lengths of the two groups under each of the four conditions are displayed in Table 1. In line with Spitz &

Table 1. *Mean digit and word span lengths of savant and control groups*

| | Digits | | Words | |
|---|---|---|---|---|
| | Forwards | Backwards | Forwards | Backwards |
| Savants | | | | |
| Mean | 5·88 | 4·00 | 4·63 | 2·63 |
| (S.D.) | (1·46) | (1·60) | (0·92) | (1·30) |
| Controls | | | | |
| Mean | 5·00 | 2·38 | 4·25 | 2·13 |
| (S.D.) | (1·31) | (2·33) | (1·17) | (2·10) |

LaFontaine (1973), the span lengths of the subjects were entered into a repeated measures analysis of variance (ANOVA) with one between-subjects factor of group (savants *v.* controls) and two within-subjects factors of item type (digits *v.* words) and direction of recall (forward *v.* backward). This revealed significant main effects of item type ($F(1, 14) = 33{\cdot}64$, $P < 0{\cdot}001$) and direction of recall ($F(1, 14) = 27{\cdot}34$, $P < 0{\cdot}001$). Thus, digits were found to be more memorable than words (means of 8·63 and 6·82, respectively) and longer spans were obtained in the forward rather than backward conditions (means of 9·88 and 5·57, respectively). There was no significant main effect of group ($F(1, 14) = 1{\cdot}72$, NS). The only interaction to reach significance was group by item type ($F(1, 14) = 6{\cdot}76$, $P < 0{\cdot}05$)). Simple effects analysis revealed that, for the savants, digits were significantly more memorable than words ($F(1, 14) = 35{\cdot}28$, $P < 0{\cdot}001$) whereas for the controls, this difference was not significant ($F(1, 14) = 5{\cdot}12$, NS). There was no significant difference between groups in either the combined digit condition ($F(1, 14) = 3{\cdot}10$, NS) or combined word condition ($F(1, 14) = 0{\cdot}51$, NS). In spite of the lack of a group by direction of recall interaction, scores for the backward recall of digits seem to suggest a trend for the savants to do better on this task than controls. However, this difference between groups was also found to be non-significant ($t(14) = 1{\cdot}63$, NS). A more conservative significance level ($P = 0{\cdot}01$) was adopted in the analysis to take account of the multiple comparisons.

The digit span results were also translated into Wechsler scaled scores. In the savant group, scaled scores ranged from 2 to 13 with a mean of 7·5 (S.D. = 3·6). For the controls, the scaled scores ranged from 2 to 10 with a mean of 5·1 (S.D. = 3·4). The difference between groups was not significant ($t(14) = 1{\cdot}36$, NS).

## DISCUSSION

Contrary to the findings of Spitz & LaFontaine (1973), the savant calendrical calculators did not show a significant STM advantage, relative to controls, on the forward digit span measure nor on the additional tests of backward digit span, forward and backward word span. Notably, the mean forward digit spans of both groups fell within the $7 \pm 2$ range. It should be noted, however, that the difference between groups was greater for the digit rather than word condition and, in addition, the difference between groups on the digits backward measure was particularly marked. It is possible that the large standard deviations along with the relatively small sample sizes masked real differences between the groups. If this was indeed the case, it would be consistent with the savants' ability not only to remember but to manipulate numerical items. However, any research which investigates subjects as rare as savants may face similar difficulties regarding group size, particularly given the variability in intelligence and level of skill observed within such a group of savant calculators (Heavey, 1997). Such difficulties serve to reinforce the importance of selecting an appropriately matched control group. The matching procedure may also go some way towards explaining the difference between the present findings and those of Spitz & LaFontaine (1973). First, unlike the 1973 study, the savants were individually matched to controls on the basis of diagnosis. This is relevant given that the majority of the present subjects have a diagnosis of autism and individuals with autism have been shown to have superior STM spans to those of ability-matched non-autistic controls (Russell *et al.* 1996). Secondly, digit span is held to be an aspect of verbal rather than non-verbal intelligence and here, unlike the 1973 study, subjects were individually matched according to verbal IQ. Consequently, it is not too surprising that their digit spans in this study were similar.

Although the present experiment failed to reveal any between group differences, the findings indicated that within the savant group immediate recall was superior for digits when compared to words. In contrast, levels of immediate recall in the control group did not differ significantly according to stimulus type. Without question, deriving knowledge of the calendar and engaging in the calculation process provides savants with extensive exposure to numerical information. Numbers are not only intrinsic to calendar structure and sequencing (e.g. 7 days in a week, 12 months in a year) and consequently to calendar rules (e.g. the 28 yearly repetition), they are also used to represent the labels denoting the basic elements of the calendar (e.g. 1 July 1964, 01.07.64). Thus, when engaged in calendar calculation or even thinking about the calendar, the savant is mentally manipulating various forms of numerically related information. This experience may well promote the memorability of digits over words for the savants, although their actual level of immediate recall remains unremarkable and in line with their intellectual ability.

Finally, the present null findings may prove informative with respect to an understanding of the development of savant date calculation ability. The skill does not appear to be subserved by superior short-term recall of numerical or word items. Moreover, this would suggest that an individual does not become a calendar calculator because they have a STM advantage relative to other individuals of the same intelligence level and diagnosis. This is consistent with findings on expertise in the normal population, which suggest that expert performance does not develop as a result of structural or 'hardware' differences between individuals, for example, differences in STM capacity and learning rate (Charness, 1988). In light of the present findings, it is possible that STM needs only to be of sufficient capacity to support the process of date calculation (a forward digit span of four being the shortest among the savants) and thus lengthier spans may not confer an added advantage in calculating dates. The lack of a relationship between the digit spans of the present group of savants and the size (in years) of their individual calculation ranges provides convergent support for this possibility (Heavey, 1997).

# Experiment 2

## INTRODUCTION

Possible explanations of savant calendrical calculation include the rote memorization of dates, visual imagery of the calendar, the use of 'anchor' dates and the utilization of calendrical rules and regularities. To differing extents, each of these explanations advocates a role for long-term memory (LTM) function in the calculation process; that is, in order to provide the correct weekday the savant must activate date information stored in LTM. Thus, if we are to gain insight into the skill by exploring the cognitive processes which subserve savant date calculation, then an investigation of LTM function is merited. This was attempted in the present experiment by: (1) exploring how the savants' existing calendar knowledge affects the long-term recall of domain-relevant information; and (2) comparing the long-term recall of savants and controls for information unrelated to the calendar.

The extent to which individual differences in existing knowledge and skill affect the acquisition of domain-related material has been extensively explored within the literature on expertise. Research has revealed that individuals with high levels of knowledge and experience in a particular domain, such as chess, physics or baseball, show marked advantages over controls for the acquisition of domain-specific information but not for the recall of general material unrelated to the area of expertise (Chase & Simon, 1973; Spilich *et al.* 1979; Charness, 1988). Generally, such differences between experts and novices are interpreted in terms of an extensively organized knowledge base that underlies the specific area of skill. Experts are better able to process information relevant to their area of excellence by relating it to their existing knowledge thus engaging in elaborative processing (Mandler, 1988; Anderson, 1990). In contrast, novices do not possess an extensive knowledge base and are, therefore, unable to relate domain-relevant information to existing knowledge structures. This results in an inferior level of recall performance relative to expert individuals.

The present group of savants are all 'experts' with the calendar. They can answer date questions spanning at least 100 years; a feat which suggests the involvement of an extensive knowledge base. The present control group can all be regarded as 'novices' with the calendar. They have a very basic knowledge of calendar concepts but do not calendar calculate, neither do they show a particular preoccupation with dates. It was, therefore, of interest to investigate whether the savants' recall performance for calendar-related and unrelated material resembled that of experts and novices in other areas: specifically, whether the difference between groups, relating to their knowledge of the calendar, influenced their ability to recall date information.

As the present experiment aimed to explore memory for calendar information in the absence of the calculation process, individual years were selected as the most appropriate stimuli (e.g. 1964, 1913, 1942). Presenting actual dates (e.g. 1 January 1975) would have provided the savants with the opportunity for calculation, which in turn may have conferred an additional processing advantage over the control subjects. As a further point of interest, two conditions involving calendar-related information were included. The first comprised individual years taken solely from the twentieth century: years which fell within the calculation ranges of all of the savant subjects. The second condition involved years taken from the eighteenth to the twenty-first century. These were years that fell, for the most part, outside of the savants' calculation spans. Of interest was whether years for which the savant is able to calendar calculate were better recalled than more distant, less familiar years. This represented a preliminary exploration of differences in recall within the area of skill, concerning the memorability of dates in relation to calculation ability.

Finally, savants and control subjects were compared on a measure of general LTM involving the recall of common nouns unrelated to the calendar. A superior level of recall in the savant group, not only for calendar-related items but also for general information, would have important implications for our understanding of savant ability. This would suggest, for example, that superior encoding, storage and retrieval processes may represent important components of savant skill. There are several lines of evidence, however, which suggest that the LTM superiority of savants over controls may not extend beyond the calendar. First, the literature on expertise shows that the LTM advantage of experts is confined solely to the area of excellence and does not extend to general information (e.g. Spilich *et al*. 1979). Secondly, this was also shown to be the case for savant mnemonists whose recall of material relating to their area of interest (bus numbers) surpassed that of IQ matched controls, although the two groups did not differ on tests of general LTM function (O'Connor & Hermelin, 1989). Thirdly, the findings of Experiment 1, which involved items not extracted directly from the calendar, revealed comparable STM performance in savants and controls. It may follow that the equivalent investigation of general LTM would reveal no basic differences between groups.

## METHOD

### Participants

The two subject groups described in Experiment 1 participated in the present experiment.

### Materials

Three conditions were presented: the recall of words, twentieth century years and years from the eighteenth to twenty-first century (mixed years). Within each condition, four lists of eight items were presented for recall. Condition 1 comprised high frequency one syllable nouns (Thorndike & Lorge, 1968). These words were judged to fall within the vocabularies of all of the subjects based on their performance on the Peabody Picture Vocabulary Test. Condition 2 comprised years taken from the twentieth century. Within each of the lists, the years were selected from a different decade and combined in a randomized, rather than chronological order. Condition 3 (mixed year condition) consisted of years taken from the eighteenth to the twenty-first century. Within each list, 2 years were selected from each century and placed in a randomized order.

### Procedure

Subjects were informed that they were to be given a test of memory. They were told that the experimenter would read out eight years/words and they should listen very carefully. After a short interval, they would be asked to remember as many of the years/words as possible in any order they chose.

The order of presentation of the three conditions was counterbalanced across savants together with their individually matched controls. Care was taken not to present Conditions 2 and 3 in close succession, due to the similarity of the items involved. Within each of the conditions, the four lists were always presented in the same order.

For all three conditions, each list was read aloud by the experimenter at the rate of one item every 3 s. This was followed by a 1 min filled interval, during which the subject was encouraged to talk with the experimenter in order to prevent verbal rehearsal. At the end of the interval, subjects were required to free recall as many of the items as possible.

## RESULTS

The mean number of words and years recalled by the savant and control groups in each of the conditions are displayed in Table 2. The total number of items recalled by each subject within each of the three conditions was entered into mixed analysis of variance with one between-subjects factor of group (savants *v*. controls) and one within-subjects factor of condition (words *v*. twentieth century years *v*. mixed years). This revealed a significant main effect of group ($F(1, 14) = 9{\cdot}82$, $P < 0{\cdot}01$) and a significant main effect of condition ($F(1, 14) = 9{\cdot}22$, $P < 0{\cdot}005$). However, these main effects were modified by a highly significant interaction between group and condition ($F(1, 14) = 16{\cdot}98$, $P < 0{\cdot}001$).

Table 2. *Mean number of words, twentieth century years and mixed years recalled by savants and controls*

| | Words | Twentieth century years | Mixed years |
|---|---|---|---|
| Savants | | | |
| Mean | 11·00 | 14·50 | 11·88 |
| (S.D.) | (5·53) | (6·35) | (5·06) |
| Controls | | | |
| Mean | 10·13 | 4·63 | 1·75 |
| (S.D.) | (5·84) | (3·46) | (1·39) |

Planned simple effects analysis revealed no significant difference between groups in terms of their recall of words ($F(1, 14) = 0{\cdot}09$, NS). The two groups differed, however, in their recall of twentieth century years ($F(1, 14) = 14{\cdot}93$, $P < 0{\cdot}005$) and mixed years ($F(1, 14) = 29{\cdot}84$, $P < 0{\cdot}005$). A series of *post-hoc t* tests was performed on the differences within groups. In view of the number of possible comparisons, a conservative significance level of $P = 0{\cdot}005$ was adopted. For the savant group, none of the comparisons between conditions reached significance: words *v*. twentieth century years ($t(7) = 2{\cdot}54$, NS); words *v*. mixed years ($t(7) = 0{\cdot}76$, NS); twentieth century years *v*. mixed years ($t(7) = 2{\cdot}84$, NS). However, for the control group words were significantly better recalled than both twentieth century years ($t(7) = 4{\cdot}08$, $P = 0{\cdot}005$) and mixed years ($t(7) = 4{\cdot}65$, $P < 0{\cdot}005$). The difference between twentieth century and mixed years did not reach significance ($t(7) = 3{\cdot}54$, NS).

The performance of subjects in the mixed year condition was further analysed. This condition comprised four lists of eight years with each list containing two years from each of the four centuries (eighteenth to twenty-first). Subjects' performance could thus be broken down to analyse the recall of years from past, present and future centuries. The mean number of years recalled from each century by the two groups is shown in Table 3. Linear contrast analysis was used to examine the total number of items recalled by each subject from each of the four centuries (eighteenth to twenty-first). For the savants twentieth century years were significantly better recalled than the other three century years combined ($F(1, 7) = 38{\cdot}90$, $P < 0{\cdot}001$) whereas for the controls twentieth century years were no better recalled than items from other centuries ($F(1, 7) = 0{\cdot}05$, NS).

## DISCUSSION

As predicted, savants recalled significantly more calendrical items from LTM when compared to the control group. Individual years, whether taken from the present century or from past and future centuries, were inherently more mem-

Table 3. *Total number of years recalled by both groups from each century within mixed year condition* (*out of a possible* 64)

| | Century | | | | |
|---|---|---|---|---|---|
| | 18th | 19th | 20th | 21st | Total |
| Savants | 4 | 21 | 53 | 17 | 95 |
| Controls | 3 | 5 | 3 | 3 | 14 |

orable for the savants. Indeed, this difference is rather extreme with the savants recalling on average over three times as many items from the twentieth century and over six times as many items from the mixed year condition than the control group. Furthermore, the two groups did not differ in their recall of words indicating that the LTM advantage of the savant group does not extend to material beyond their area of skill and thus appears to be calendar-specific. The comparable performance of both groups on a measure of general LTM function would also suggest that the factors which predispose such individuals to become calendar calculators do not include generally superior encoding, storage and retrieval processes.

The recall advantage of savants over controls for year items suggests that the calculators have access to an extensive knowledge-base concerning the calendar. Even though the savant is unable to perform the process of calculation on the single years, nevertheless, these items must lend themselves to a form of elaborated processing. In effect, individual years are more meaningful to the savant because they can be related to a substantial amount of existing knowledge. All of the date calculators in the present sample have a strong interest in calendar information relating to events, such as the dates of various outings, the dates on which all of the clients joined their day-centre (Heavey, 1997). Not only is this source of knowledge available, but more importantly, they can calendar calculate over a range of these years, therefore possessing extensive knowledge regarding the day-date pairings within these individual years. It is, thus, unsurprising that such a rich database of calendar knowledge would promote the recall of year items even in the absence of the calculation process.

Furthermore, it would follow that savant knowledge relating both to events and to the calculation of dates would favour the recall of twentieth century years. All events of personal significance to the savant would have occurred within their own lifetime or at least within the present century. Moreover, the twentieth century represents the period of the calendar that falls within the calculation spans of all the savants. Some support for the memorial advantage of twentieth century years was obtained from the present findings. Although the savants' recall of items from the twentieth century condition and mixed year condition did not differ significantly, there appears to be a non-significant trend in the predicted direction. Furthermore, the recall levels obtained by savants in the mixed year condition may have been inflated by the inclusion of twentieth century years in these lists. When presented with years spanning four different centuries, the majority of items recalled by the savants were from the present century, a pattern of performance not observed in the control group. Indeed, the proportion of items recalled by the savants from the eighteenth to twenty-first centuries is notable in that it appears to map the calculation range of the group as a whole (see Table 3). While all of the savants can calculate across the present century, the spans of some of the group extend into the nineteenth and twenty-first centuries. In other words, when presented with a range of different years, the pattern of recall appears to reflect the dates they can calculate.

Finally, the finding that savants remember words and years equally well may appear somewhat contradictory to the results of Experiment 1 in which numerical items were better recalled than words. The superiority of digits in the immediate recall task may reflect not only the savants' experience with the calendar but also the use of items taken from a limited set (i.e. digits 1 to 9). This contrasts with the word span test in which items were drawn from a less restricted pool (Roth & Crosson, 1985). In Experiment 2, however, both the years and words were selected from a wide range of possible items. Moreover, the comparable level of recall for words and years in the savant group suggests that date information may be as extensively represented in LTM as knowledge relating to words.

# Experiment 3

## INTRODUCTION

Although savant calendrical calculators, when compared to control subjects, do not exhibit generally superior STM and LTM function, they do show better mnemonic performance within the domain of the calendar. This finding is interpreted in terms of the encoding of individual year items in relation to the savants' existing knowledge of dates. In the present experiment, memory for calendrical information was investigated further by examining the direct effect of calendar calculation on the long-term retention of dates. This involved comparing the savants' memory for dates following separate calculation and study tasks. A difference in the memorability of calculated and studied dates would suggest differential activation of the savants' calendar knowledge-base, thus highlighting the specific operations involved in generating the weekday of a given date as opposed to processing a date for which no calculation is required.

Relevant to the theoretical interpretation of the present experiment is the general cognitive literature on the 'generation effect' (e.g. Slamecka & Graf, 1978). It has been demonstrated that individuals are better able to retain words that they have generated (e.g. having to provide the word 'slow' in response to the semantically related cue fast–s____) than externally provided words they are required to read (e.g. in the form fast–slow): an experimental design which mirrors that adopted in the present experiment. This effect may be explained in terms of the increased elaboration resulting from the generation process: in order to generate the word, connections within the knowledge-base are activated which subsequently provide multiple access routes to the concept to be retrieved. In contrast, the activation which results from reading an item may be concentrated largely on the specific representation(s) for that word. Evidence that the generation effect depends on a structured knowledge base derives from several sources. First, Nairne *et al.* (1985) obtained an effect of generation over study only for medium and high frequency words and not for low frequency and non-words. According to the authors, this could be interpreted in terms of the greater number of associative links between higher frequency words and other entries within the lexicon. That is, generating information which is not part of an elaborate interrelated network results in a very limited or no generation effect. Secondly, Reardon *et al.* (1987) explored the generation effect with a group of individuals judged to have an expert level of knowledge of psychology and participants whose knowledge of psychology was minimal. Both groups were also given equivalent generate and study tasks in an area (sports trivia) about which they were judged to have a comparable level of knowledge. A generation effect was obtained only for the experts and only within their area of expertise. The authors concluded that the generation effect arises from the utilization of a richly interconnected knowledge base which in turn facilitates the process of elaboration thereby promoting the memorability of generated items.

In line with this theoretical interpretation, obtaining a 'generation effect' for dates in the present group of savant calculators would thus support the view that a structured knowledge base underlies their calendar calculation ability and moreover the process of calculation utilizes the connections and interrelations within this knowledge store.

## METHOD

### Subjects

Eight savant calendrical calculators participated in the present experiment. Although two of the individuals included in the previous experiments were unavailable for testing, two additional savants had been recruited to the study. Both individuals were able to calculate across the present century. Within the group, six individuals had received a reliable diagnosis of autism and two of the savants were regarded as having non-specific mental handicap. Mean chronological age was 34·4 years (S.D. = 8·0). Mean verbal IQ, as measured on the Peabody Picture Vocabulary Test, was 65·6 (S.D. = 12·9). Non-verbal IQ scores obtained from the Ravens Progressive Matrices Test were also available for the present group (mean of 77·9 (S.D. = 23·0)).

The requirement for calendar calculation within the current experimental procedure precluded the use of a non-calculating control group.

## Materials

The experiment involved two conditions: the first of which required subjects simply to study/read the dates and the second which required the calculation of dates. Each condition also comprised a recognition memory test.

### *Study condition*

Subjects were presented with a list of 18 dates to study/read. Each date comprised not only the year and month but also the corresponding weekday (see Table 4). In order to construct this list, three sets of six dates were selected to fall on one of three days: Monday, Thursday and Sunday. The recognition phase of the experiment required subjects to identify the Monday dates presented within this study list. Thus, the Thursday and Sunday dates served as 'filler' items. Within each of these three subgroups, the dates were selected to span an equivalent year range: the Monday dates fell from 1919 to 1984, the Thursday dates ranged from 1923 to 1987 and the Sunday dates spanned 1918 to 1982. The 18 dates were then combined in a randomized order to form the list presented to subjects for study.

The recognition test comprised a list of 10 dates which included five of the dates falling on a Monday from the original study list. The remaining five items were 'distractor' dates which also fell on a Monday. These distractors were taken from years which fell 2 years into the past and future from the target years and were thus from a comparable year range. The distractor and target dates were placed in a randomized order within the list.

### *Calculation condition*

As in the above condition, a list of 18 dates was presented. However, this list did not contain the respective weekdays of the dates (see Table 4). Again, the list was constructed using three groups of items falling on different weekdays: Monday, Tuesday and Friday. As in the study condition, this task required the Monday dates to be recognized in the subsequent test of memory. Thus, the Tuesday and Friday dates served as 'filler' items. The three subgroups of dates were selected to span an equivalent year range. For example, the Monday dates spanned from 1918 to 1983 which was comparable with that used in the study condition. The Tuesday dates ranged from 1922 to 1990 and the Friday dates spanned 1919 to 1981. These dates were placed in a randomized order to form the list presented to subjects for calculation.

The recognition test for the calculation condition comprised 10 dates, all of which fell on a Monday. Five of these dates were taken from the original list presented for calculation. The remaining five dates were distractor Mondays, taken from an equivalent year range as the target Mondays. The order of targets and distractors was randomized within the list.

All lists in both conditions were presented to subjects on sheets of A4 card, printed in double line spacing and in Times Roman 20pt sized font. An additional piece of A3 card was used, which contained a small window cut into the card, large enough to reveal only one date at a time within the list.

## Procedure

The present experiment utilized two design features regarded as optimal in eliciting the effect of generation over study for words: incidental memorization (Watkins & Sechler, 1988) and recognition rather than recall (Serra & Nairne, 1993). Thus, following the study and calculation tasks, memory was assessed in the form of a surprise recognition test. In addition, recognition may be regarded as a more exhaustive test of memory than recall (e.g. Shanks & St John, 1994) and as the present experiment was perceived to involve an increased memory load relative to Experiment 2 (in the form of longer lists of items and the presentation of actual dates rather than individual years) recognition rather than recall performance was examined in order to render the task less difficult.

The order of presentation of conditions was alternated between savants and the two conditions were administered in separate testing sessions.

### *Study condition*

Subjects were informed that they were to be shown a list of 18 dates and the experimenter would examine whether they could read the

Table 4. *Format of dates presented in Experiment 3 together with mean responses*

| Condition | Example of date presented | Mean number of dates recognized (out of 5) Mean | (S.D.) |
|---|---|---|---|
| Study of date followed by recognition test | Monday 7 January 1980 | 2·9 | (0·6) |
| Calculation of date followed by recognition test | 24 January 1927 | 5·0 | (0·0) |

dates. It was stressed that they should look at the items very carefully and think about what they were reading. It was also stressed that they would not need to calculate the dates as the weekdays would be included in the list. In this way, the test was disguised as a measure of reading ability with emphasis also placed on the subject studying the date carefully.

The A3 cardboard window was used to reveal only one of the dates at a time in an attempt to focus the savants' attention on the individual items. Each date was displayed for a period of 5 s during which the savant was required to read the date aloud. When all 18 dates had been displayed in isolation, the cardboard window was removed and the whole list was available to study for an additional 15 s. Although the savants can calculate most twentieth century dates in $< 5$ s, this 15 s study period ensured that more time was provided for the savants to process the dates in the study rather than calculation condition. Following a 5 min interval, during which the experimenter talked generally with the subject, the surprise recognition list was presented. Subjects were told that the list contained some of the Monday dates that they had read on the previous list. It was stressed that not all of the dates on the new list would have been seen previously. However, the subjects were not told how many dates they should identify from the 10 items on the recognition list.

### *Calculation condition*

Subjects were informed they were to be given a test of calendar calculation. There would be 18 dates, which they should try and calculate as accurately as possible and they would be told whether they were right or wrong at the end of the list. As in the study condition, dates were displayed individually within the A3 cardboard window, which was moved down to the next date immediately after a weekday had been generated for the previous date. Unlike the study condition, the full list was not presented for additional inspection time. A 5 min interval followed the removal of the list, during which the experimenter attempted to engage the subject in conversation. After the interval, the recognition list containing 10 Mondays was placed in front of the subjects. They were informed that some, but not all, of the items would be dates they had previously calculated. As in the study condition, the savants were not told how many of these dates they were expected to identify.

## RESULTS

All subjects were able to read and calculate the full set of items presented. The number of Monday dates correctly identified from the two recognition lists were evaluated to take account of false positive responses, which applied to two subjects in the study condition only. The mean number of dates correctly recognized in each condition is shown in Table 4. In the calculation condition the savants performed at ceiling, recognizing all of the dates presented (mean of 5·0, S.D. $= 0·0$). Fewer dates were correctly identified in the study condition (mean of 2·9, S.D. $= 0·6$). Analysis using the Wilcoxon matched-pairs, signed-ranks test revealed a significant difference between conditions ($Z = 2·52$, $N = 8$, $P < 0·05$).

## DISCUSSION

The results reflected the ease with which the savants remembered the calculated when compared with the studied dates. Indeed, their memory for the calculated dates is impressive given the size of the individual items (comprising date, month and year) and the number of filler dates included in the original calculation list. This difference in the memorability of calculated when compared to studied dates has implications for an understanding of the operations involved in the date calculation process. In line with the theoretical reasoning proposed to explain the effect of generation over study for words, the process of calendar calculation appears to involve the use of an elaborate, interconnected knowledge base. Whereas studying a date together with its respective weekday may result in the activation of the specific representation(s) for that date, generating the weekday makes additional use of the interconnections between date representations. In turn, this activation of relational links facilitates subsequent memory by providing an increased number of access and retrieval routes to the previously presented date. It would, thus, appear that savants utilize connections between dates stored in LTM as part of the calendar calculation process.

An alternative interpretation of the current findings should be considered, however. The enhanced memorability of calculated items may be attributable to the increased mental effort and additional attentional resources required by the date calculation process. Although this suggestion cannot be addressed directly within the present experimental design, studies of the generation effect in the general population, using words rather than dates, are relevant. These demonstrate that engaging in an effortful process to generate an item does not necessarily give rise to the effect of generation over study. Nairne *et al*. (1985) did not obtain an effect when subjects were required to generate low frequency and non-words. Reardon *et al*. (1987) did not obtain the effect for participants outside of their area of expertise. If the generation effect was simply attributable to an increase in the cognitive resources required for the generation process then the effect would be evident on all tasks that require generation. Rather, the effect appears to be limited to tasks which utilize an elaborately structured knowledge-base.

## GENERAL DISCUSSION

As all of the proposed explanations of savant calendar calculation implicate memory as a component of the skill, the present study focused on the memory performance, as distinct from the calculation ability, of a group of calendar savants. Tests of general short- and long-term memory (Experiments 1 and 2) did not reveal a savant recall advantage over verbal IQ and diagnosis matched controls. However, tests of long-term memory for calendrical information, which involved the recall of individual years, revealed a clear savant superiority relative to controls (Experiment 2). Such findings suggest that a calendar-related knowledge base underlies the skill of date calculation. For the savants, the individual years could be encoded in relation to existing knowledge, thus promoting their memorability. The superior retention of calculated dates when compared to studied dates provided further evidence of the activation of calendar information stored in LTM (Experiment 3). This 'generation effect' for dates suggests that the process of date calculation makes use of the structure and interrelations within this knowledge base. In discussing these findings, we concentrate on the following issues: (1) how the calendar knowledge-base may be structured and the means by which this gives rise to the actual calculation process; (2) whether there are certain analogues between date calculation ability and other savant skills; and (3) the relationship between savant calendrical calculation and a diagnosis of autism.

In order to conceptualize how the activation of structured representations may underlie savant date calculation, it is necessary to consider the format in which calendar information is stored in LTM. Evidence suggests that the savants' knowledge of dates reflects the internal structure of the Gregorian calendar. This is apparent in their use of calendrical rules and regularities as part of the calculation process (Hermelin & O'Connor, 1986; Ho *et al*. 1991). Furthermore, an extension of the present study revealed that savant calculators recalled significantly more dates from lists linked according to structural features of the calendar (e.g. the 28-yearly repetition, leap years) than from lists of structurally unrelated dates (Heavey *et al*. 1998*b*). Indeed, given that the calendar is characterized by internal consistency, being governed by both large scale regularities and smaller recursive patterns, it is unsurprising that an organized knowledge-base would develop from continued exposure to such highly structured date information. The key point, however, is that the actual 'algorithm' or method for calculating dates is embedded within the structure of the calendar and thus mirrors an individual's experience with the instrument (Norris, 1990). In this respect, the calendar is distinctive in that an internalization of the relationships between its individual components can give rise to a generative process: that is, structural knowledge of how one date relates to another date permits the generation of the appropriate weekday.

Such a view of savant date calculation ability is consistent with findings on other savant skills. Savant musical knowledge reflects the rule-governed structure of music enabling not only the reproduction (e.g. Charness *et al*. 1988) but also the generation of music in the form of improvisation and composition (e.g. Hermelin *et al*. 1989). Thus, through a series of generative 'rules' the savant is able to combine individual notes to produce phrases and larger musical structures and in this respect does not differ from musicians of normal intelligence (Miller, 1989). Similarly, artistic savants are able to produce realistic perspective without the use of an explicitly formulated perspective system (Mottron & Belleville, 1995). From the savants' day-to-day experience of pictorial representations, they are able to transform the three-dimensional world onto a two-dimensional surface approximating such perspective devices, even though these 'rules' may never have been consciously extracted (Hermelin & Pring, 1998). The calculation skills of numerically able savants appear to develop from an interest in and familiarity with the number system, enabling the extraction of numerical regularities and structure which in turn permits the use of mathematical short-cuts and rules (e.g. Stevens & Moffitt, 1988). Thus, not only in calendar calculation but in other savant talents, experience and knowledge of relationships and structure within a restricted area can yield a generative output. Furthermore, the calendar shares with domains such as music and mathematics, the feature of being a closed system. It has its own internal rules and regularities and, thus, can be appreciated without reference to a broader context (Miller, 1989).

Concerning the relationship between autism and specific abilities, it is important to note that though there are many more mentally handicapped people without autism, most savants are autistic. Indeed, of the ten savant calculators who participated in the present study, eight are diagnosed as having the disorder. Thus, dispositions associated with autism at the behavioural level, such as repetitive and obsessive tendencies (Hermelin & O'Connor, 1991) and/or at the cognitive level may play a role in the development of date calculation skills. In relation to other savant talents, it has been proposed that a deficit in hierarchical organization may be linked not only to cognitive processing in autism but also to savant mnemonic (Mottron *et al*. 1996) and artistic ability (Mottron & Belleville, 1993, 1995). Whereas in the normal population a preferential status is assigned to the global level of processing, in autistic savants both the global and local level are suggested to be given an equivalent status. Such a deficit in hierarchical organization would prevent top-down processes from influencing low-level perceptual representations and in the case of autistic artists, for example, would permit an accurate graphic reproduction of what is directly perceived. This explanation is clearly related to the hypothesis of 'weak central coherence' in autism (Frith, 1989; Happé, 1994). Normal information processing is characterised by the tendency to interpret information in a global fashion, to integrate information at different levels. This enables us to derive meaning from diverse information and to take account of context. This facet of cognitive processing is suggested to be impaired in individuals with autism, resulting in a tendency to process information in a piecemeal rather than global way. Support for this theory includes the superiority of individuals with autism over controls on an embedded figures task (Shah & Frith, 1983) and the Wechsler block design test, with the advantage of the autism subjects resulting from an enhanced ability to mentally segment designs into their constituent parts (Shah & Frith, 1993). Recent research involving graphically gifted autistic savants suggests that such a 'segmentational' processing style is associated not only with a diagnosis of autism but also with artistic talent (Pring *et al*. 1995). Both the savant group and an artistically able control group (comprising children matched to the savants on the basis of non-verbal mental age) were significantly faster at mentally 'decomposing' and reassembling picture puzzles than control groups without artistic ability. Weak central coherence may thus be one facet of cognitive processing which predisposes individuals with autism to develop artistic ability. Similarly, a tendency towards local rather than global processing may play a role in savant musical ability. Absolute pitch, the ability to identify and label single note frequencies without relating the information to other pitches, is reported to be universally present among savant musicians (Miller, 1989). In addition, musically naive autistic children are better able to identify and remember isolated notes than mental age matched controls (Heaton *et al*. 1998).

How then might the local processing style associated with autism facilitate the acquisition of savant calendrical skills? It is suggested that the savants' knowledge of the calendar develops from the processing of isolated dates or 'fragments' of the calendar. Certainly, many individuals with autism have an interest in birthdays often from an early age and also have an excellent memory for the dates of events such as holidays and day trips. Through continued experience of single day-date pairings the individual becomes exposed to calendar regularities and repetitions. For example, taking an interest in the current weekday and date would provide exposure to weekly/7-day repetitions; every eighth date falls on the same weekday. Exposure to calendar regularities would then facilitate the recombination of knowledge, with new date information continuing to be integrated within the knowledge store. In turn, the knowledge-base evolves to mirror the structure of the calendar. This reformulation of knowledge would then give rise to the use of calendrical rules, even though such rules may never have been consciously extracted. Finally, the use of calendar structure and rules permits the knowledge-base to generalize to new dates for which the corresponding calendars have never been directly studied. Thus, the calendar knowledge-base is able to generate weekdays to questions concerning dates which were never explicitly processed or deliberately memorized by the savant, such as dates in the far future. This account is consistent with Norris' (1990) connectionist model of savant date calculation in which savants are not suggested to extract calendar rules directly. Rather, learning is instance-based, derived from many examples of individual dates, with the knowledge base reorganizing itself to reflect the structural patterns detected within the incoming input. This tendency for processing isolated dates may thus represent an important precursor of savant calendar calculation. Indeed, a strong preoccupation with birthdays and the dates of individual events was characteristic of all the savants included in the present study, as reported by parents and carers (Heavey, 1997). Furthermore, preliminary support for a link between segmentational processing and savant date calculation ability derives from the significant positive correlation between Wechsler block design performance (a proposed marker for weak central coherence) and size of calculation span observed in the present group of savants (Heavey, 1997). Thus, there appears a need for the future investigation of calendar savants to consider not only the mechanisms which directly subserve the process of date calculation but also the cognitive factors that play a role in the acquisition of such an unusual skill.

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