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Executive functions in savant artists with autism

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Abstract

Although executive functions have been widely studied in individuals with autism spectrum disorders (ASD), there have been no direct empirical studies of executive abilities in savants with ASD. This study assessed three facets of executive ability – fluency, perseveration and monitoring – in savant artists with ASD, compared to non-talented adults with ASD or moderate learning difficulties (MLD). Executive functions were assessed in and out of the savants' domain of expertise; on design fluency and card sort tasks, respectively. The design fluency task revealed the executive abilities of savant artists to be spared, relative to the non-talented ASD group; an effect not observed on the card sort task. Islets of ability may therefore serve as protective factors against domain-specific cognitive deficits in ASD.

Key Words: autism; savants; executive functions; art; fluency; card sort.

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Executive functions in savant artists with autism

The term ‘executive function’ refers to a number of higher-order cognitive operations such as planning, working memory, mental flexibility, inhibition, generativity and action monitoring (Rabbitt, 1997). Initially, this term was coined to describe the impairments observed in patients with frontal lobe lesions (Duncan, 1986) and, consequently, these abilities have been linked to the frontal structures of the brain, particularly the prefrontal cortex (Stuss & Alexander, 2000). Executive impairments have also been observed in several developmental disorders that are thought to involve frontal lobe deficits, including autism spectrum disorder (ASD) (Hill, 2004a, 2004b). However, despite several studies documenting executive difficulties in both children and adults with ASD (e.g., Hill & Bird, 2006; Robinson, Goddard, Dritschel, Wisely, & Howlin, 2009), there have been no direct empirical studies of executive function in savants with ASD.

The term ‘savant’ was originally coined to refer to individuals with an outstanding ability in a specific area who had low levels of intelligence (Down, 1887); a definition later extended to include individuals with average or above average intelligence (Miller, 1999). The majority of savants are diagnosed with ASD (Pring, 2005), with savant abilities being reported in 9.8% of this group (Rimland, 1978, although see Howlin, Goode, Hutton, and Rutter, 2009, for a higher estimate). Savant skills have been noted in a wide range of domains, including memory (Treffert, 2009), music (Sloboda, Hermelin, & O'Connor, 1985), calendar calculation (Heavey, Pring, & Hermelin, 1999), arithmetic

(Heavey, 2004), poetry (Dowker, Hermelin, & Pring, 1996) and, the focus of this paper, art (Pring, Hermelin, & Heavey, 1995).

Anecdotal accounts of savant artists with ASD have been commonly documented. Selfe (1977; 1983), for example, reported the case of Nadia, who was diagnosed with ASD and displayed severe language and behavioural difficulties, yet possessed an incredible ability to draw. Likewise, Sacks (1995) and others (e.g., Pring, Hermelin, Buhler, & Walker, 1997) have studied the work of architectural artist Stephen Wiltshire, who was diagnosed with ASD at the age of three and later developed a prodigious artistic skill (see Figure 1 for an example of Stephen's work). Accounts such as these led Hermelin, O'Connor and colleagues to initiate a comprehensive programme of experimental research on this group (see Hermelin, 2002, for a review). In particular, these studies have stressed the domain-specific nature of savant talent; for example, the superior memory performance commonly associated with savant artists has only been observed on tasks involving drawing skill (O'Connor & Hermelin, 1987). Overall, this research suggests that motor control is a central skill for savant artists.

[place Figure 1 about here]

Despite a wealth of psychological research on savant artists, the executive abilities of this group are a hitherto neglected topic. It is, however, possible to glean some indication of the executive skills of this group. First, the observation that savant artists produce their artistic outputs spontaneously indicates that they do not appear to suffer from the generativity impairments commonly observed in groups with ASD (e.g., Turner, 1999). Second, the process of developing a piece of artwork involves the conscious control of behaviour (Lezak, 1995; Mottron, Belleville, & Ménard, 1999), as well as planning, goal setting and monitoring (Thomas & Silk, 1990; Van Sommers, 1989). Third, several authors have commented that savant artists rarely, if ever, make mistakes in their artwork that require altering or erasing (e.g., Mottron & Belleville, 1995; Sacks, 1995; Selfe, 1977, 1983). From this observation, one could conclude that the planning and monitoring skills of savant artists are intact. In support of this hypothesis, savant artists are found to perform better than control participants when monitoring their motor behaviour on a mirror drawing task (Hermelin, Pring, & Heavey, 1994).

In summary, it appears that savant artists may show spared executive abilities relative to their non-talented counterparts with ASD, at least in the domain of their ability. However, there are some observations that question this hypothesis. First, the reports that savant artists rarely amend their artistic outputs does not mean that they do not make errors. Instead, this lack of correction could be interpreted as evidence of a *lack* of monitoring. Second, Selfe (1977) noted that the savant artist Nadia paid no attention to drawing her outputs in the centre of the page (as also noted by Sacks, 1995, in his reports of savant artist Stephen Wiltshire). Rather, she began drawing anywhere on the page and frequently drew off the edges; not behaviour associated with a well-planned approach. This observation suggests that the accuracy and ability observed in savants' artistic outputs might result from factors such as semantic independence (drawing what is seen rather than known, with no interest in the viewer's perspective) or highly accurate visuo-kinaesthetic programming, rather than enhanced executive abilities in areas such as planning or monitoring. Finally, it has been noted that savant artists show reduced thematic variation in their artwork (Hermelin, Pring, Buhler, Wolff, & Heaton, 1999; Pring et al., 1997), which might be associated with a lack of flexibility (although this has also been observed in artists without ASD).

To date, there have been no direct empirical assessments of executive abilities in savant artists with ASD. Such an investigation could determine if savant artists experience the same cognitive impairments as non-talented individuals with ASD, or whether their artistic ability results in a sparing of these processes. A further topic of interest regards whether the executive abilities of savant artists are dependent upon the domain of assessment, in view of the reports of preserved cognitive processes in savant artists on tasks requiring drawn responses only (O'Connor & Hermelin, 1987). To address these aims, the current study assessed savant artists with ASD on executive function tasks requiring a drawn or a non-drawn response; a design fluency task (Jones-Gotman & Milner, 1977) and the Wisconsin Card Sort Task (Grant & Berg, 1948; Heaton, 1981), respectively. These tasks were selected as both assessed executive abilities in the domains of fluency, perseveration and monitoring; skills that are particularly relevant to creative performance. To evaluate the performance of the savant artists, they were compared against non-talented adults with ASD (to evaluate the role of artistic talent), as well as adults with moderate learning difficulties (MLD) (to assess whether any impairments were syndrome-specific). It was predicted that the non-talented ASD group would perform poorer than the MLD group, in view of the common reports of executive impairments in ASD. However, no predictions were made regarding the performance of the savant artist group, as evidence supports the notion of both preserved and impaired executive abilities in this group (as previously discussed).

Method

Participants

Nine savant artists with ASD participated in this research; five were diagnosed with autism, three with Asperger syndrome and one with atypical autism. These participants ranged in age from 23 to 43 (mean = 34.55, SD = 5.13) and comprised seven males and two females. They were recruited from an existing database of graphically gifted savants, through specialist services affiliated to the National Autistic Society (UK), and by contacting savant artists following local art exhibitions. Upon recruitment into the study, examples of artwork from each savant were assessed by an independent art examiner, who rated their work as being of a standard that would gain them entry into art school. For all participants in this study, verbal IQ (VIQ) was assessed using the Peabody Picture Vocabulary Test (Dunn & Dunn, 1997) and performance IQ (PIQ) was assessed using Raven's Standard Progressive Matrices (Raven, 1960) or Raven's Coloured Progressive Matrices (Raven, 1956). The mean VIQ of the savant group was 83.66 (SD = 17.49) and their mean PIQ was 84.00 (SD = 18.50).

The savant artists were individually matched to participants in two non-talented comparison groups on the basis of age, gender and IQ. The first comparison group comprised nine adults with a formal diagnosis of ASD; five were diagnosed with autism, three with Asperger syndrome and one with atypical autism (as in the savant artist group). Their mean age was 32.22 (SD = 6.59) and they comprised seven males and two females. These participants were recruited from a day centre for adults with ASD run by the National Autistic Society (UK). None of the participants in this group displayed any artistic talent, although several took part in art sessions at their day centre. Their mean VIQ was 78.78 (SD = 14.79) and their mean PIQ was 82.33 (SD = 16.59).

The second comparison group comprised eight adults with general learning difficulties who did not have a diagnosis of ASD or any related pervasive developmental disorder. These participants were recruited from a local adult education centre and comprised individuals with a variety of developmental disorders, general learning difficulties and mental health problems. A brief screening measure, adapted from the Autism Diagnostic Observation Schedule (Lord et al., 1989) was used to ensure that none of the participants in this group had an undiagnosed ASD. One further participant (recruited from the University of London) was included in this group, to match the relatively high IQ of one of the savant artists (whose mean VIQ was 111 and PIQ was 114). This group therefore comprised seven males and two females, whose mean age was 32.55 (SD = 5.77). The mean VIQ of this group was 95.11 (17.86) and their mean PIQ was 83.55 (19.19). None of the participants in this group displayed any artistic ability.

Materials

Design Fluency: The design fluency task (Jones-Gotman & Milner, 1977) is a non-verbal analogue to the commonly used word fluency tasks. As such, this is a particularly useful task when assessing executive function in groups with language difficulties. This task comprised two conditions: free and fixed. In the free condition, participants were informed that they were taking part in a pattern drawing task and that they were to draw as many designs or patterns as they could in four minutes[i]. Importantly, they could not draw real shapes or objects; they had to make up the patterns themselves and could not scribble. The experimenter emphasised the instructions by depicting and explaining two acceptable and two unacceptable designs (see Appendix for examples). Participants were then told to draw as many patterns or designs as possible, making each drawing different to the last. As the aim of this task, in part, was to examine monitoring and perseveration in light of negative feedback, participants were given three warnings for each type of mistake made (as suggested by Turner, 1999). These mistakes included the production of a recognisable shape or object, scribbling, drawing identical or very similar designs, and drawing very elaborate designs. Participants were praised for all acceptable responses.

In the fixed condition, participants were informed that they were to complete the same task, but this time each response must only have four lines. A line was described to participants as a single line that did not have a sharp corner. The experimenter further explained this instruction by illustrating what was accepted as a line (i.e., a circle, curve or spiral could be counted as a line) and by drawing several acceptable and unacceptable responses (see Appendix for examples). Participants were also asked to name which of several exemplars would or would not be acceptable in the current task. Again, participants were given three warnings for each type of mistake (in this condition, warnings were given for the same errors as in the free condition, as well as for using the wrong number of lines). Participants were also praised for each acceptable response.

In both conditions, responses were scored on several parameters (in line with guidelines presented by Jones-Gotman and Milner, 1977, and subsequently used by Turner, 1999). First, responses were scored on the basis of *overall fluency*. This referred to the total number of responses generated, irrespective of any repeats, scribbles or inappropriate responses. Second, *perseverative responses* were calculated, which comprised the total number of responses that were rotations of preceding items, variations on a theme, designs that varied from a former response by a single detail, scribbling, or exact repetitions. For this measure, only the percentage scores were used, to reduce the confounding effect of low fluency scores (as suggested by Jones-Gotman & Milner, 1977, and Turner, 1999). Finally, *novel responses* comprised the total number of responses produced, minus any perseverative errors, recognisable responses or designs with the incorrect amount of lines. This provided a measure of how well participants adhered to the rules given at the start of the task and their overall monitoring ability.

All participants completed the free condition before the fixed condition, with a break of a few minutes given in between the two conditions.

Wisconsin Card Sort Task: The WCST (Grant & Berg, 1948; Heaton, 1981) consists of two packs of 64 cards and 4 stimuli cards, which differ in colour, form and number. Following Nelson (1976), all cards sharing more than one attribute with a stimulus card were removed. This resulted in 24 cards from the original set being suitable. To make the length of the test adequate, two packs were combined, resulting in 48 test cards. In this task, the participant was required to sort a pack of cards according to a rule that was not disclosed by the examiner. Participants were not informed of the purpose of the task; only that they were to sort the cards and after each card has been placed the examiner would tell them whether they were correct or incorrect. The rules (colour, shape and number) were alternated after the participant had correctly sorted six or ten cards correctly, but they were not informed that the rule had changed, so needed to use the examiners feedback to guide them to the correct response. Specifically, for correctly placed cards participants were told *'that is very good, that is the rule I was thinking of'*, and for incorrectly placed cards participants were told *'that is not the rule I am thinking of, try again'*. After each card was laid, it was left in place and incorrect cards were not returned to the pack. The sorting principle changed after six cards were consecutively placed correctly, following the colour, number, shape order. However, in line with Goldman, Axelrod and Tompkins (1992), participants were not explicitly instructed when to change principle. In addition, following Nelson (1976), the test was discontinued after six categories had been successfully sorted, or the pack of 48 cards was exhausted. Prior to the WCST experimental trials, a training condition was implemented in which the experimenter gave three cards to the participant and instructed them to match one card to the stimulus card according to each of the three rules. All participants were able to complete this initial trial. Following the training task, practice cards were added back to the original pack and the experimental trials were administered.

The WCST was scored on several parameters. First, the total number of correct categories was calculated. As a category consisted of six correctly sorted cards in order, the maximum number of categories was six. Next, the total number of incorrectly scored cards was counted, giving a total error score. The categorisation of errors followed that outlined by Heaton (1981). First, the number of perseverative errors (responses that would have been correct at the previous stage) was calculated. There were two exceptions to this rule. The first related to perseverative errors that occurred before a category had been completed. In this case, participants could perseverate on the basis of the first incorrect card placed. The second type of perseverative error related to perseverative errors that arose *within* a stage of the test. This occurred when the participant began to sort incorrectly and perseverated on this incorrect response, even though the incorrect response was not the preceding correct response. In these instances, the ‘perseverated to’ principle changed after three cards were incorrectly placed in the way outlined above. The number of perseverative errors was then subtracted from the total number of errors to give the total of non-perseverative errors. As all participants sorted the same amount of cards, the total error scores are illustrated, rather than percentage scores.

Procedure

The current research was conducted as part of a larger investigation into cognition in savant artists (also see Pring, Ryder, Crane, & Hermelin, under review). All participants were tested individually in a quiet room at their day centre. Here, the IQ tests were administered first, followed by the design fluency task (in which the free condition preceded the fixed condition, with a break of a few minutes separating the two tasks). Finally, the WCST was administered.

Results

Design fluency

Overall fluency: the total number of responses

The performance of the three groups in the free and fixed conditions, as well as an overall score, is presented in Table 1. A 2 (condition: free or fixed) x 3 (group: savant, ASD or MLD) mixed design ANOVA revealed there to be a significant main effect of condition, $F(1, 24) = 4.35$, $p < .05$, which indicated that all participants produced fewer responses in the fixed condition than the free condition. A significant main effect of group was also observed, $F(1, 24) = 4.78$, $p < .05$. Bonferroni corrected independent-samples t-tests demonstrated that the savant and MLD groups produced a significantly higher number of responses than the ASD group ($t = 3.23$, $p < .01$), whilst there was no significant difference between the scores of the savant and MLD groups ($p > .05$). Finally, no significant interaction effect was observed ($p > .05$).

[placeTable 1 about here]

Perseverative responses: the number of repeats of visually similar responses

To maintain suitable power when analysing error scores, only the combined scores for the two conditions are discussed (as in Turner, 1999). The mean percentage of perseverative responses drawn by the savant artists was 27.26 (SD = 21.32). This was very similar to that of the ASD (mean = 29.27, SD = 22.12) and MLD (mean = 26.53, SD = 16.55) groups. This was confirmed by the results of a Kruskall-Wallis analysis, which indicated that there were no significant group differences on this measure ($\chi^2 = 0.05$, $p > .05$).

Novel responses: the number of acceptable responses

The percentages of novel or acceptable responses in each condition, as well as overall percentages, are presented in Table 2. A 2 (condition) x 3 (group) mixed design ANOVA revealed there to be a significant main effect of condition, $F(1, 24) = 11.40$, $p < .01$, as there was a significantly higher percentage of novel responses in the free, relative to the fixed, condition. Although there was no significant interaction effect, $F(1, 24) =$

0.34, $p < .05$, there was a trend towards a main effect of group, $F(2, 24) = 2.66$, $p = .09$. As it is the performance of the savant artists relative to the ASD group that is of particular interest, an independent samples t-test was conducted to compare the results of these two groups. This revealed that the savant artists produced a significantly higher percentage of acceptable responses than the ASD group ($t = 2.07$, $p < .05$).

[place Table 2 about here]

Finally, the free and fixed condition scores were combined for measures of overall fluency, perseverative responses and novel responses, and these were entered into a correlation matrix with IQ scores. This revealed that in the MLD group, VIQ and PIQ were significantly associated with overall fluency scores (VIQ: $r = .70$, $p < .05$; PIQ: $r = .69$, $p < .05$) and novel response scores (VIQ: $r = .84$, $p < .01$; PIQ: $r = .75$, $p < .05$). However, there were no significant correlations between IQ and design fluency in the savant artist or ASD groups.

Wisconsin Card Sort Task

The mean scores (SD) for each of the measures obtained on the WCST are illustrated in Table 3

[place Table 3 about here]

A series of one-way ANOVAs conducted on the category, F (2, 24) = 0.55, $p <$ .05, total error, F (2, 24) = 0.50, $p < .05$, and other error, F (2, 24) = 0.28, $p < .05$, scores revealed there to be no significant group differences. Due to the high standard deviations for the perseverative errors, a Kruskall-Wallis test was used to analyse this data, which also revealed there to be no significant group differences ($\chi^2 = 0.89$, $p > .05$).

Performance on these measures was also correlated with IQ. In the MLD group, significant correlations were observed between VIQ and the number of categories (r = .75, $p < .05$), total errors ($r = -.76$, $p < .05$) and other errors ($r = -.65$, $p < .05$) but not perseverative errors ($r = -.55$, $p > .05$). However, as on the design fluency task, there were no significant correlations between IQ and WCST performance in the two groups with ASD.

Discussion

The aim of the current study was to assess executive abilities (specifically, fluency, perseveration and monitoring) in savant artists with ASD, relative to non-talented individuals with ASD or MLD. Participants were assessed on tasks both in and out of the savants' domain of expertise – on a design fluency task and a card sort task, respectively. Results demonstrated that the fluency and monitoring performance of the savant artists was superior to that of the ASD comparison group on the design fluency task (i.e., on a task in their domain of ability). However, no significant differences were observed between the savant, ASD and MLD groups on the card sort task (i.e., on a domain-general task).

The key finding from this study was the preserved performance of the savant artists on the fluency and monitoring aspects of the design fluency task. Whilst the non-talented group with ASD displayed deficits in these areas, the savant artists scored similarly to the MLD group on this measure. This suggests that, in the domain of their talent, savant artists have enhanced executive abilities, relative to their non-talented counterparts. Despite this, no significant group differences were observed regarding the perseveration measure of the design fluency task. This finding contrasts with previous research (Turner, 1999), which demonstrates that individuals with ASD generate higher rates of disallowed or perseverative responses than groups with MLD. One possible explanation for this is that the design fluency task is not a good measure of perseveration, as it does not require an individual to overcome a previously reinforced or prepotent response. However, as noted by Turner (1999) and Jarrold (1997), perseverative errors are more apparent in tasks that provide few environmental cues, regardless of previous feedback. Nevertheless, it is important to stress that the mean scores produced by the two groups with ASD in this study are similar to those obtained by Turner (1999). Although Turner examined numbers of repeats separately, rather than providing an overall perseveration score, when the performance of her low and high functioning groups with ASD are combined, similar levels of perseveration are found to that in the current study (approximately 25%). It therefore appears that, using Turner's participants as a comparison, it is the performance of the MLD group that is particularly poor, rather than the two groups with ASD displaying intact performance. Importantly, the savant artists showed no sparing of ability relative to the ASD comparison group on the perseveration aspect of the design fluency task.

The savant artists were also found to score similarly to ASD group (and to the MLD group) on the WCST; a task outside of their domain of ability. This suggests that the spared fluency and monitoring abilities observed in the savant artists on the design fluency task are domain-specific. This finding is consistent with the results of several empirical studies, which demonstrate that the preserved or superior performance of savant artists on a range of psychological tasks is only apparent on tasks involving a drawn repsonse (Hermelin, 2002; O'Connor & Hermelin, 1987). One explanation for this is that the savant group possess superior visual-motor monitoring abilities, in that they are better able to relay the visual information of what they were drawing back to motor control, to produce an acceptable response. This is consistent with Turner's (1999) suggestion that due to the abstract nature of the design fluency task, participants were not required to preformulate a response, hence they were more reliant on visual feedback to monitor their responses. In Turner's study, individuals with ASD were particularly poor at this. However, this appears not to be the case in the savant artists with ASD in this study. These results, which suggest that savant artists are better able to monitor their responses and feedback visual information to motor control, are also consistent with previous results obtained with savant artists on a mirror drawing task (Hermelin et al., 1994).

The suggestion that individuals with ASD have difficulties with action monitoring and error correction was also raised by Russell and Jarrold (1998). They suggested that the problems encountered by this group arose from difficulties in generating visual schemas and using visual feedback effectively. Using a computerised tennis game, they found that children with ASD were less able than controls at correcting visible errors (i.e., making corrections when the tennis ball and players were visible on the computer screen; termed ‘external corrections’), as well as correcting responses that had yet to become apparent errors (i.e., making corrections when the tennis ball and players were no longer visible on the computer screen; termed ‘internal corrections’). They concluded that the failure to produce internal corrections resulted from their failure to generate an adequate visual schema for the action taken, whereas the failure to correct external errors resulted from their greater efficiency at using motor feedback rather than visual output. These suggestions are consistent with the results of the design fluency task and with the style of drawing favoured by savants, in which they rarely amend outputs by erasing (cf. Sacks, 1995; Selfe, 1977). It may therefore be that the superior performance of the savant artists on the design fluency task, and the incredible accuracy associated with their artwork, result from their ability to construct visual schemas. This explanation is certainly consistent with previous findings in which savants artists have superior motor programming ability (O'Connor & Hermelin, 1987) and are better at recalibrating novel visual feedback with motor ability (Hermelin et al., 1994).

However, it is important to stress that the WCST not only failed to discriminate between the savant artist and ASD groups, but also the ASD and MLD groups. This might appear somewhat surprising, as the WCST is one of the more consistent measures in identifying ASD-specific deficits (Liss et al., 2001). However, there are several possible explanations for this. First, executive function performance is known to be compromised in various other clinical disorders and it is likely that the mixed aetiology of the MLD group may have masked any group differences. However, as the performance of the MLD and savant groups was significantly above that of the ASD group on the design fluency task, this explanation is not convincing. Second, it might be that the WCST is not sensitive enough to discriminate between the ASD and MLD groups. Several researchers have noted that tests of executive function often fail to discriminate between groups with low levels of intelligence, with consistent results only being obtained in higher functioning groups (e.g., Griffith, Pennington, Wehner, & Rogers, 1999). Overall, it is important for future research to assess savant artists (and groups with ASD or MLD) on a wider range of executive tasks, both in and out of their domain of ability. This will provide more convincing support for the domain-specific nature of spared executive abilities in savant artists suggested in this paper. However, this research should be balanced against the methodological issues involved when assessing individuals of low intelligence on cognitively demanding executive tasks.

References

Dowker, A., Hermelin, B., & Pring, L. (1996). A savant poet. *Psychological Medicine, 26*, 913-924.

Down, J. (1887). *On some of the mental affections of childhood and youth*. London: Churchill.

Duncan, J. (1986). Disorganisation of behaviour after frontal lobe damage. *Cognitive Neuropsychology, 3*(3), 271-290.

Dunn, L., & Dunn, L. (1997). *Peabody Picture Vocabulary Test* (3rd ed.). Circle Pines, MN: American Guidance Service.

Goldman, R. S., Axelrod, B. N., & Tompkins, L. M. (1992). Effect of instructional cues on schizophrenic patients' performance on the Wisconsin Card Sorting Test. *American Journal of Psychiatry, 149*(1718-1722).

Grant, D. A., & Berg, E. (1948). A behavioral analysis of degree of reinforcement and ease of shifting to new responses in a Weigl-type card-sorting problem. *Journal of Experimental Psychology, 38*(4), 404-411.

Griffith, E. M., Pennington, B. F., Wehner, E., & Rogers, S. J. (1999). Executive Functions in Young Children with Autism. *Child Development, 70*(4), 817-832.

Heaton, R. K. (1981). *A manual for the Wisconsin Card Sorting Test*. Odessa, FL: Psychological Assessment Resources.

Heavey, L. (2004). Arithmetical savants. In A. Baroody & A. Dowker (Eds.), *The development of arithmetic concepts and skills: Recent research and theory*. Oxford: Oxford University Press.

Heavey, L., Pring, L., & Hermelin, B. (1999). A date to remember: the nature of memory in savant calendrical calculators. *Psychological Medicine, 29*(1), 145-160.

Hermelin, B. (2002). *Bright splinters of the mind: a personal story of research with autistic savants*. London: Jessica Kingsley.

Hermelin, B., Pring, L., Buhler, M., Wolff, S., & Heaton, P. (1999). A visually impaired savant artist: Interacting perceptual and memory representations. *Journal of Child Psychology and Psychiatry, 40*, 1129-1139.

Hermelin, B., Pring, L., & Heavey, L. (1994). Visual and motor functions in graphically gifted savants. *Psychological Medicine, 24*(3), 673-680.

Hill, E. L. (2004a). Evaluating the theory of executive dysfunction in autism. *Developmental Review, 24*(2), 189-233.

Hill, E. L. (2004b). Executive dysfunction in autism. *Trends in Cognitive Sciences, 8*(1), 26-32.

Hill, E. L., & Bird, C. A. (2006). Executive processes in Asperger syndrome: Patterns of performance in a multiple case series. *Neuropsychologia, 44*(14), 2822-2835.

Howlin, P., Goode, S., Hutton, J., & Rutter, M. (2009). Savant skills in autism: psychometric approaches and parental reports. *Philosophical Transactions of the Royal Society B: Biological Sciences, 364*(1522), 1359-1368.

Jarrold, C. (1997). Pretend play in autism: executive explanations. In J. Russell (Ed.), *Autism as an Executive Disorder* (pp. 101-142). Oxford: Oxford University Press.

Jones-Gotman, M., & Milner, B. (1977). Design fluency: The invention of nonsense drawings after focal cortical lesions. *Neuropsychologia, 15*(4-5), 653-674.

Lezak, M. (1995). *Neuropsychological Assessment*. Oxford: Oxford University Press.

Liss, M., Fein, D., Allen, D., Dunn, M., Feinstein, C., Morris, R., et al. (2001). Executive functioning in high-functioning children with autism. *Journal of Child Psychology and Psychiatry and Allied Disciplines, 42*(2), 261-270.

Lord, C., Rutter, M., Goode, S., Heemsbergen, J., Jordan, H., Mawhood, L., et al. (1989). Austism diagnostic observation schedule: A standardized observation of communicative and social behavior. *Journal of Autism and Developmental Disorders, 19*(2), 185-212.

Miller, L. (1999). The savant syndrome: Intellectual impairment and exceptional skill. *Psychological Bulletin, 125*, 31-46.

Mottron, L., & Belleville, S. (1995). Perspective production in a savant autistic draughtsman. *Psychological Medicine, 25*(3), 639-648.

Mottron, L., Belleville, S., & Ménard, E. (1999). Local Bias in Autistic Subjects as Evidenced by Graphic Tasks: Perceptual Hierarchization or Working Memory Deficit? *The Journal of Child Psychology and Psychiatry, 40*(05), 743-755.

Nelson, H. (1976). A modified card sorting response sensitive to frontal lobe defects. *Cortex, 12*, 313-324.

O'Connor, N., & Hermelin, B. (1987). Visual and graphic abilities of the idiot savant artist. *Psychological Medicine, 17*(1), 79-90.

Pring, L. (2005). Savant talent. *Developmental Medicine and Child Neurology, 47*(7), 500-503.

Pring, L., Hermelin, B., Buhler, M., & Walker, I. (1997). Native Savant Talent and Acquired Skill. *Autism, 1*(2), 199-214.

Pring, L., Hermelin, B., & Heavey, L. (1995). Savants, Segments, Art and Autism. *Journal of Child Psychology and Psychiatry, 36*(6), 1065-1076.

Pring, L., Ryder, N., Crane, L., & Hermelin, B. (under review). Creativity in savant artists with autism. *Psychological Medicine*.

Rabbitt, P. M. A. (Ed.). (1997). *Methodology of Frontal and Executive Function*. Hove: Psychology Press.

Raven, J. (1956). *Guide to using the Coloured Progressive Matrices*. London: H.K. Lewis.

Raven, J. (1960). *Guide to using the Standard Progressive Matrices*. London: H.K. Lewis.

Rimland, B. (1978). Inside the mind of the autistic savant. *Psychology Today, 12*(3), 69-80.

Robinson, S., Goddard, L., Dritschel, B., Wisely, M., & Howlin, P. (2009). Executive functions in children with Autism Spectrum Disorders. *Brain and Cognition, 71*(3), 362-268.

Russell, J., & Jarrold, C. (1998). Error-Correction Problems in Autism: Evidence for a Monitoring Impairment? *Journal of Autism and Developmental Disorders, 28*(3), 177-188.

Sacks, O. (1995). *An anthropologist on Mars*. London: Picador.

Selfe, L. (1977). *Nadia: A case of extraordinary drawing ability in an autistic child*. London: Academic Press.

Selfe, L. (1983). *Normal and anomalous representational drawing ability in children*. London: Methuen.

Sloboda, J. A., Hermelin, B., & O'Connor, N. (1985). An exceptional musical memory. *Music Perception, 3*, 155-170.

Stuss, D. T., & Alexander, M. P. (2000). Executive functions and the frontal lobes: a conceptual view. *Psychological Research, 63*(3), 289-298.

Thomas, G. V., & Silk, A. M. J. (1990). *An introduction to the Psychology of Children's Drawing*. Hemel Hempstead: Harvester-Wheatsheaf.

Treffert, D. (2009). The savant syndrome: an extraordinary condition. A synopsis: past, present, future. *Philosophical Transactions of the Royal Society B: Biological Sciences, 364*(1522), 1351-1358.

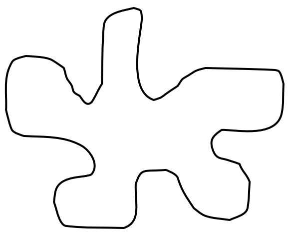
Turner, M. (1999). Generating Novel Ideas: Fluency Performance in High-Functioning and Learning Disabled Individuals with Autism. *Journal of Child Psychology and Psychiatry, 40*, 189-201.

Van Sommers, P. (1989). A system for drawing and drawing-related neuropsychology. *Cognitive Neuropsychology, 6*(2), 117-164.

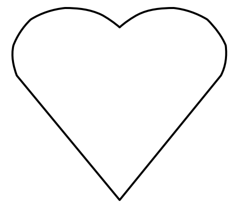
Appendix

Examples of acceptable and unacceptable responses in the free and fixed conditions of the design fluency task.

Free condition:

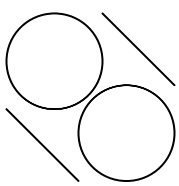


Acceptable response

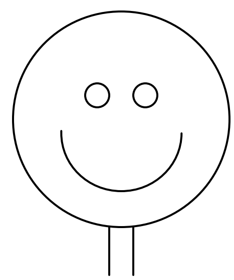


Unacceptable response (real object)

Fixed condition:



Acceptable response



Unacceptable response (real object and incorrect number of lines)

Author note

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Table 1: Mean (SD) overall fluency scores of the savant, ASD and MLD groups on the design fluency test

	Condition		
	Free	Fixed	Total
Savant artists	14.22 (8.20)	15.11 (8.20)	29.44 (14.54)
ASD	7.44 (4.69)	4.56 (2.51)	12.33 (6.40)
MLD	15.67 (8.23)	11.11 (7.82)	27.56 (15.59)

Table 2: The percentage (SD) of novel responses produced by the savant, ASD and MLD groups on the design fluency test

	Condition		
	Free	Fixed	Overall
Savant artists	72.37 (28.76)	42.10 (28.46)	57.06 (23.70)
ASD	46.57 (25.30)	26.79 (25.35)	37.92 (14.38)
MLD	64.68 (26.12)	47.09 (28.89)	57.20 (21.62)

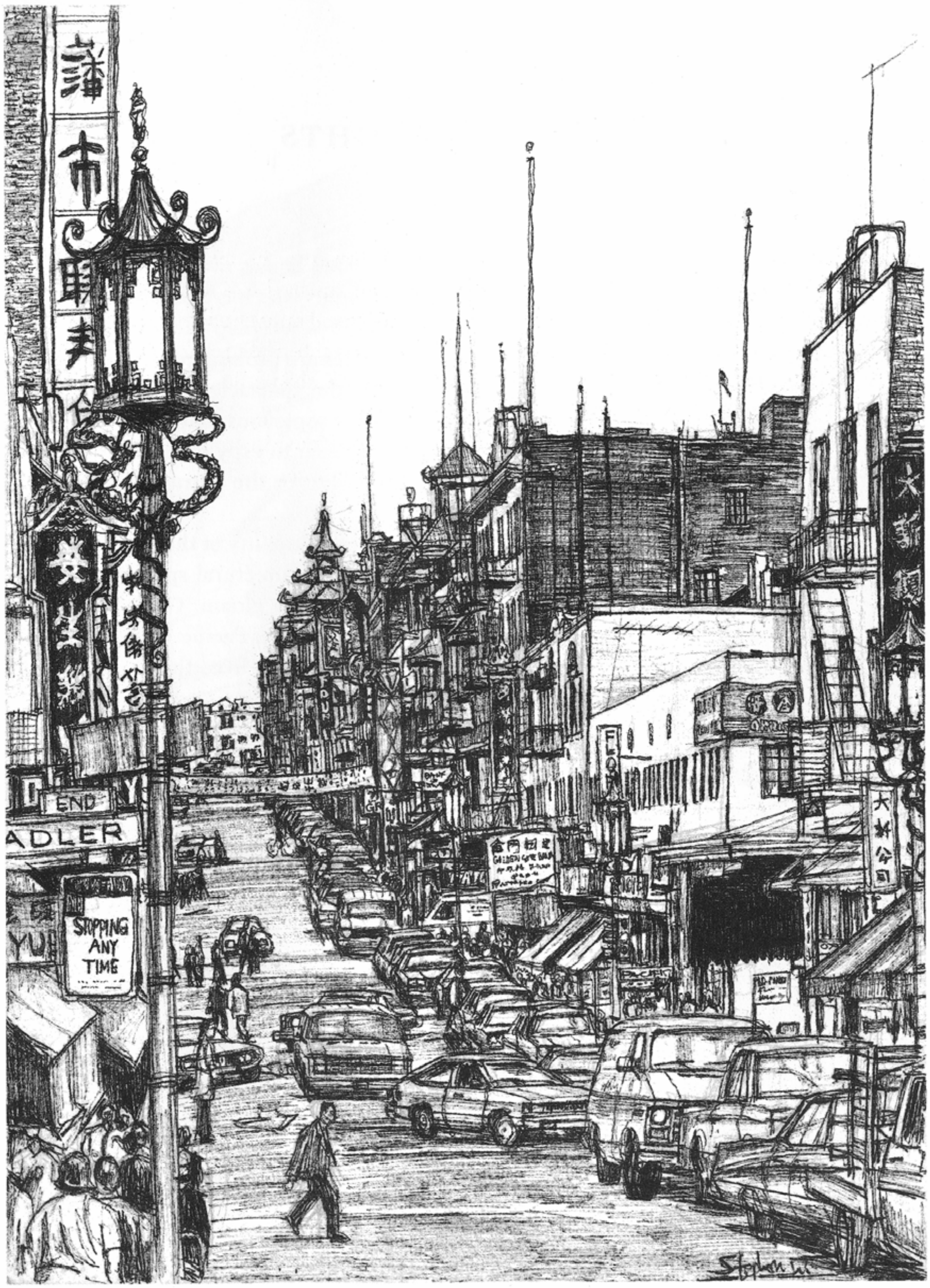
Table 3: Mean (SD) scores of the savant, ASD and MLD groups on the WCST

	Categories	Total error	Perseverative error	Other error
Savant artists	3.44 (2.07)	17.22 (10.66)	10.22 (8.18)	7.00 (5.74)
ASD	2.44 (1.81)	21.89 (9.49)	14.11 (7.11)	7.78 (3.56)
MLD	2.89 (2.20)	17.44 (13.08)	11.56 (10.25)	5.89 (6.51)

Figure Captions

Figure 1: Example artwork from savant artist Stephen Wiltshire (now in the Stephen Wiltshire Gallery, London, UK)

Figure 1- top



Footnotes

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[i] In Jones-Gotman and Milner's (1977) study, a time limit of five minutes was imposed in the free condition, which was reduced to four minutes on the fixed condition. The reasoning behind this variation was that the responses drawn in the free condition were more complex than those in the fixed condition. However, pilot testing for the current study revealed that the responses drawn in both conditions were very simple. Therefore, to make performance in both conditions comparable, a time limit of four minutes was imposed in both conditions.