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Profiling executive dysfunction in adults with autism and comorbid learning disability

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Abstract

Executive dysfunction is thought to be primary to autism. We examined differences in executive function between 20 adults with autism and learning disability and 23 individuals with learning disabilities outside the autistic spectrum. All participants were matched for chronological age and full-scale IQ, and were given a battery of tasks assessing fluency, planning, set-shifting, inhibition and working memory. Analyses of the individual tasks revealed very few significant differences between the two groups. However, analyses of composite scores derived for each executive domain revealed that the group with autism showed impaired performance on the working memory and planning tests. Together, these two measures were sufficient to classify participants into their diagnostic groups significantly better than would be expected by chance (75% of the autism group; 65% of the control group). Executive impairments were neither universal nor exclusive to the autism group, and we suggest that an alternative cognitive theory may better explain the cognitive profile we found.

Diagnosis of autism is typically based upon impairments in social interaction, particularly communication, and restricted, repetitive, stereotyped behaviours (American Psychiatric Association, 1994). Much research has focused on impoverished social functioning, leading to the speculation that specific socio-cognitive deficits lie at the heart of behaviours observed across the autism spectrum (e.g. Baron-Cohen, 2002; Baron-Cohen et al., 2000). However, many of the non-social behavioural characteristics of autism are also observable in patients with damage to the frontal and pre-frontal cortical areas associated with executive function (EF) (e.g. Duncan, 1986). Accordingly, recent years have seen the emergence of studies exploring the relationship between autism and executive dysfunction (e.g. Hill, 2004; Ozonoff et al., 2004; Pennington and Ozonoff, 1996).

Executive function is an umbrella term used to describe the processes involved in the preparation and implementation of action (for a detailed overview see Stuss and Knight, 2002). Markers of executive dysfunction include difficulty in initiating action, planning ahead and inhibiting inappropriate responses (where inflexible thinking results in perseveration with those inappropriate responses), and the absence of strategy monitoring. Hill's (2004) review of the relationship between autism and EF focused on the most commonly observed traits of executive dysfunction: planning, inhibition, set-shifting, generativity (fluency) and action monitoring. However, findings from the various research programmes are difficult to compare due to a number of factors: different studies explore different EF domains, studies do not tend to assess a range of domains within the same participant group, and participants' chronological and mental age are not directly comparable. This is especially true for adult populations; the majority of research has tested children and adolescents.

For the present study, we examined five executive domains – planning, inhibition, set-shifting, fluency and working memory – in two very closely matched populations. Before describing the study itself, it is worthwhile outlining briefly each of the domains under scrutiny in turn.

Planning. Planning involves the identification and organization of steps needed in order to achieve a goal (Lezak, 1995), and often demands consideration of a number of alternatives before selecting the one most likely to achieve that goal. Using Tower of London or Tower of Hanoi type tasks (where the goal is to rearrange discs or coloured balls in order to replicate an existing arrangement in as few moves as possible), children and adolescents with autism have been found to be impaired (e.g. take more moves, or make more errors) compared to normally developing age- matched controls (Ozonoff et al., 1991). Rumsey and Hamburger (1988) found similar results in adults. However, there is evidence that group deficits are dependent upon the intellectual level of participants. Planning deficits in autism are evident when participants' intelligence quotient (IQ) falls within the learning disabled range (Hughes et al., 1994) but not when IQ is in the normal range (Ozonoff et al., 2000).

Inhibition. Inhibition is fundamental to selectively attending to goal-related stimuli whilst ignoring interfering stimuli, thereby preventing habitual (i.e. prepotent) responses. Variations on the classic Stroop task (Stroop, 1935) have revealed that, unlike other facets of executive functioning, autistic children and adolescents display similar levels of interference compared to normally developing age-matched controls (Eskes et al., 1990; Ozonoff and Jensen, 1999). Although autism-related deficits have been found in adult populations (e.g. Rumsey, 1985; Rumsey and Hamburger, 1988), the effect of IQ remains in question (Hill, 2004).

Set-shifting (sometimes called cognitive flexibility). This refers to the ability to shift from one line of responding to another (e.g. consistently responding to one dimension of a stimulus before being required to inhibit this response and instead respond to an alternative dimension). As for planning, children, adolescents and adults with autism are less likely to change responses where appropriate, compared to age- and IQ-matched controls (Ozonoff and Jensen, 1999; Rumsey, 1985). However, there is similar evidence that these differences are dependent upon the intellectual level of participants; no differences were found when IQ fell within the normal range (Ozonoff et al., 2000; Turner, 1997).

Fluency. Fluency refers to the ability to generate multiple, specific, responses. For example, asking participants to produce as many words beginning with ‘S’ as they can in 1 minute assesses word fluency. Ideational fluency tests examine the ability to generate novel ideas (e.g. how many uses can be found for a hat) while tests of design fluency might ask participants to produce as many different patterns using the same grid in 1 minute. This is an area of research where adult populations seem particularly under-represented, although Turner (1999) found that individuals with autism generate fewer novel words and ideas, and produce less complex designs, than verbal IQ-matched controls.

Working memory. In addition to the four domains cited in Hill (2004), we also examined working memory. Working memory refers to the ability to simultaneously process and store information whilst performing cognitive tasks (e.g. Baddeley, 1986). The majority of, if not all, executive tasks rely on working memory typically because they demand holding a rule in mind whilst responding. However, there are a number of paradigms that would seem to employ working memory in isolation from other executive facets. Both low- and high-functioning groups with autism have been assessed with working memory paradigms. The results have been mixed. Bennetto et al. (1996) found a high-functioning group to be impaired on a number of working memory tasks compared to a chronological age (CA) - and IQ-matched heterogeneous clinical group. In contrast, no working memory impairments were found in a learning disabled (Russell et al., 1996) and a high-functioning group with autism (Bebko and Ricciuti, 2000).

A pattern of impairments and preserved skill is emerging in individuals with autism. Set-shifting, fluency, planning and possibly working memory appear to be impaired, whilst inhibition has been found to be intact (see also Pennington and Ozonoff, 1996; Pennington et al., 1997). However, this picture looks less clear when we start to compare findings across studies. Extensive as the research to date has been, studying clinical populations makes it difficult to compare like with like; participants typically differ on at least one of the dimensions of age and intellectual level, and studies are often limited to testing one or two executive domains. Similarly, different studies often employ different matching criteria for control groups. Thus, whilst there are sufficient grounds for acknowledging an executive-deficit theory, the available data are problematic. It is difficult to determine just which aspects of cognitive dysfunction are typical to autism and which are not (Hill, 2004).

Autism is often associated with learning disability.[1] As with other epidemiological factors associated with autism, there are discrepancies in the proportion of people thought to have comorbid learning disability. Estimates suggest that between 65 and 85 percent of children with autism also have learning disabilities (Gillberg and Coleman, 2000). The diagnosis of learning disability is based upon the presence of two factors prior to the age of 18 years: substantially impaired general intellectual functioning compared to the general population (an IQ of 70 or less), and significant limitations in adaptive functioning. Accordingly, one of the difficulties in reviewing the available research on the executive function theory of autism is that EF covers a number of domains and autism covers a broad range of intellectual functioning.

The preliminary investigations we report here are an attempt to address this particular concern. In sum, much of the existing research in this area has (1) failed to administer a comprehensive executive battery to a single autism population, (2) given scant attention to adults and (3) ignored similarities between the autistic profile of executive dysfunction and that observable in non-autism populations. The aims of the present study were twofold. In response to (1) and (2), we set out to assess five executive domains in a single adult population clinically diagnosed with autism. In response to (3) we compared this clinical population with a matched control group of adults identified as having similar levels of intellectual functioning but who are not diagnosed as having autism.

Method

Participants

Fifty-three patients from a local health trust in Northumberland, England, were contacted and asked to take part in the research, of which 48 gave consent. Ethical approval was obtained from Northumberland Local Research Ethics Committee and Northgate and Prudhoe NHS Trust Research and Development Committee. Three patients were subsequently excluded because they were unable to perform any of the tasks (despite falling into the appropriate IQ range) and two were excluded because their IQ fell outside the range specified for the study, namely full scale intelligence quotient (FSIQ) 50 to 85 (mild learning disability 50–70, borderline intellectual functioning 70–85: American Psychiatric Association, 1994). All subjects underwent a semi-structured psychiatric interview. Twenty satisfied DSM-IV criteria for autism and comorbid learning disability (learning disability), and 23 for learning disability but no autism (American Psychiatric Association, 1994). All participants were males aged between 18 and 45 years.

The two groups were explicitly matched on verbal IQ (VIQ) and CA, and there were no significant differences between the groups in terms of performance IQ (PIQ) or FSIQ (see Table 1).

Table 1 **Verbal IQ (VIQ), performance IQ (PIQ), full-scale IQ (FSIQ) and chronological age (CA) of participants**

ure	*n group* *0)* *(SD)*	*ol group* *23)* *(SD)*	*t*
	68 (6.8)	69 (7.3)	0.78
	69 (9.1)	71 (8.6)	0.78
	67 (7.0)	69 (7.5)	0.78
	30 (9.0)	32 (9.2)	1.02

Procedure

The five domains of executive functioning were assessed as follows.

Planning. Two tests of planning ability were used: a simplified analogue of the Tower of London test, from the Neuropsychological Assessment Battery (NEPSY) test battery (Korkman et al., 1998), and the Mazes task from the Weschler Intelligence Scale for Children–Version III (WISC–III: Wechsler, 1992). For the Tower of London task the participant is presented with a wooden structure comprising three vertical pegs of differing lengths, and three wooden balls. The task is to move the balls from a pre-specified starting position in order to match a target configuration, in the fewest number of moves, moving only one ball at a time, within a specific time limit. The level of difficulty increases from simple one-move problems to more complex seven-move problems, and there were two or three trials of each level of difficulty. The task was abandoned if the participant failed all problems at a given level. Dependent variables include number of moves taken to solve each problem, completion time and type of errors (moving two balls at once, not completing the problem, discontinuing, out of time and incorrect solution).

The Mazes task consists of a series of 10 increasingly complex mazes. Participants were told to ‘help the person in the middle get to the exit’, and avoid making line-cross errors (i.e. when the participant crosses a ‘wall’ of the maze) and blind-alley errors (when the participant must retrace their steps). Exceeding the stated time limit or a threshold number of errors for any given maze was classed as a fail, and the test was discontinued if the participant failed two consecutive mazes. Dependent variables are time taken to complete each maze, number of mazes completed, and number and types of errors made.

Inhibition. We used two measures to examine participants’ ability to inhibit responses: the first level of the Knock and Tap task from the NEPSY test battery (Korkman et al., 1998) and the Verbal Conflict task (adapted from Elders, 1998). For the Knock and Tap test the participant was taught to tap on the table with their palm when the experimenter knocked on it with her knuckles, and vice versa. Fifteen trials were presented in a pseudorandom order. Dependent variables include number of correct responses, number of errors and types of errors. Errors fall into two categories: copying errors (producing the same response as the experimenter) and other errors.

For the Verbal Conflict task the participant was presented with a piece of A4 black card with a picture of a moon on it and a piece of A4 white card with a picture of a sun on it. The aim is to point to the black card when the experimenter said ‘day’ and point to the white card when the experimenter said ‘night’. Dependent variables include number of correct responses, number of errors and number of corrected responses (this refers to any responses where the participant hesitated above one response, but then selected the alternative choice).

Set-shifting. The modified Wisconsin Card Sorting Task (WCST–m) comprises four stimulus cards and 48 response cards (Elders, 1998; Lezak, 1995) that differ across three dimensions: colour, shape and number. The cards can be sorted by using one of three rules (colour, shape or number). The participant sorts six consecutive cards by the same rule, then the participant is told that the rule has changed and that they must sort by a new rule. For the first three (simple) trials, the participant was told which rule to sort by, but on subsequent (complex) trials they had to choose and employ a new rule that was different from the previous one. Dependent variables include total number of cards sorted correctly, total number of errors, total number of perseverative errors, total number of other types of error and total number of trials attempted.

Fluency. Two fluency tasks were used, one verbal and one non-verbal. The verbal measure was performance on the Controlled Oral Word Association (COWA) task (Lezak, 1995). Participants were given 1 minute to generate as many words that they could think of that began with the letter F, and repeat for letters A and S. Dependent variables are based on performance of all three trials, and include total number of words produced, total number of correct words produced, number of perseverations, number of rule breaks (a non-word or a word that does not begin with the given letter) and number of words produced during the four quarters of the minute.

As a measure of non-verbal fluency we used a design fluency task taken from the NEPSY test battery (Korkman et al., 1998). The participant was shown a series of identical arrays of five dots and asked to join two or more dots with straight lines in order to make a different design for each array. The time limit was 1 minute. The dependent variables are total number of designs produced, total number of valid designs produced, number of perseverations, number of rule breaks (failure to join the dots) and number of designs produced during the four quarters of the minute.

Working memory. The Spatial Span Task from the Wechsler Memory Scale–III (Wechsler, 1997) was adapted for this group, although only the ‘forward’ condition was used. The apparatus comprised a spatial span board consisting of a plastic base with 10 randomly arranged identical plastic cubes protruding from the top. The sides of the cubes facing the participant were blank, but the sides facing the experimenter were numbered from one to 10. The experimenter points to a sequence of blocks according to the numbers on the back, at a rate of one cube per second, and participants must reproduce the pattern. The complexity of this task increases as a factor of the length of the trial (i.e. the number of blocks in the sequence). The dependent variable corresponds with the number of correct trails reproduced.

In addition to the five executive domains, we also used the following control task.

Map Mission. We included a Map Mission task to assess filtering/searching attention, which has been shown to be intact in autism (Burack et al., 1997). This control task was included to test the possibility that any problems that participants had on the executive functioning tasks could not be attributed to more generic attentional impairments that might affect performance on our dependent variables. The participant was given 1 minute to search an A3 replica of an Ordnance Survey map for symbols (knives and forks) and to circle as many as possible, whilst ignoring distractor symbols.

Results

When violations to parametric assumptions prevented the use of ANOVA and *t*-tests, non-parametric ANOVA and Mann–Whitney *U*-tests were employed. A significance level of $p < 0.05$ was adopted for all analyses (two-tailed). We had a large number of dependent variables, and the usual convention when making multiple comparisons is to apply a Bonferroni correction to reduce the risk of a type I error. However, we do not report Bonferroni corrections here for two reasons: Bonferroni correction has been accused of being too conservative (Altman, 1997), and our sample size was small. We were concerned that taking a conservative approach might mask any potentially meaningful differences, and one of our major objectives was to obtain findings that would generate future research. Accordingly, we would encourage the reader to treat any significant differences with caution.

Notwithstanding this statistical caveat, effect sizes were also calculated for each dependent variable using Glass's *d* (Glass, 1976) as a means of interpreting statistical differences according to Cohen's (1988) effect size index (i.e. where 0.2 refers to a small difference, 0.5 to a moderate difference and 0.8 or more to a large difference).

Before examining performance on the executive tasks, we checked the data to rule out possible non-executive explanations for group differences. First, we checked the data for the three tasks (word fluency, design fluency and Map Mission tasks) where it was possible to determine whether or not either group fatigued more easily (any group difference may be mediated by one group tiring more easily). On all three tasks there were no significant group differences in terms of the number of responses made within each quarter of the allotted time. Second, we compared performance on the Map Mission control task. Non-parametric analyses failed to reveal any significant group differences in either the number of symbols identified or the mean number of errors made (0.00 for the control group and 0.05 for the group with autism).

In addition, notwithstanding the fact that the two groups were well matched on IQ and attention measures, we wanted to check whether any of these potential covariates was exerting a greater influence on one group more than the other on the EF tasks. Accordingly, in each case where performance on an EF task correlated with PIQ, FSIQ or performance on the Map Mission task for either group, we ran between-group comparisons, entering the three respective measures as covariates in turn. However, these analyses did not affect the following results.

Performance in the five executive domains

For the sake of economy, only statistically significant results of analysis on each of the multiple measures taken for each task are reported in the text. However, we also compare the number of participants in each group who passed each of the tests. Passing or failing was determined by classifying each participant according to whether they exceeded an arbitrary passing criterion, which in all cases was set as the mean value of the respective task means of the two groups. We wanted to identify which, if any, of the domains under scrutiny should be included in an autism-specific profile of executive dysfunction and which are common to learning disability within the same IQ range. Participants scoring above this combined mean were classified as having passed the test, and those that had a score equal to or below the mean were classified as having failed the test. These pass/fail data were then subjected to a two-sample chi-squared test.

Planning. Although the group with autism consistently performed worse than the control group on both the Tower of London task and the Mazes task, on all response measures none of these differences reached significance. There are, however, two trends in these data that approach significance. First, more people in the control group passed the Tower task (59% versus 30%): $X^2(1, N = 42) = 3.58$, $p = 0.06$. Second, although there was no significant difference in the number of people passing the Mazes task (52% versus 42%), the group with autism made more line-crossing errors on the Mazes task: $U = 157.5$, $p = 0.07$; effect size $d = 0.74$.

Inhibition. As expected, we found no significant differences between the groups on either the Knock and Tap test task or the Verbal Conflict task, although there was a moderate effect size ($d = 0.68$) on the Verbal Conflict task. There were no significant differences between the groups in terms of the number of people passing and failing the Knock and Tap task (x^2 $(1, N = 39) = 0.655$, $p > 0.10$) or the verbal conflict task ($x^2(1, N = 40) = 0.143$, $p > 0.10$).

Set-shifting. Although the group with autism performed consistently worse than the control group on all dependent variables, none of these reached statistical significance. Furthermore, there were no significant group differences in the number of people passing and failing: $X^2(1, N = 39) = 2.820, p > 0.05$).

Fluency. We assessed both word fluency and design fluency. In both cases, the absolute number of correct responses is the primary measure. In addition, the perseverative error score is thought to be a measure of the ability to disengage from one response and engage in another response (i.e. it is a measure of set-shifting). Given the inherent impairments in language associated with autism, it was important to ensure that the group with autism were able to perform the word fluency task. Exploration of the means reveals that both groups, on average, were able to produce more than one word every 10 seconds in the verbal condition, which is comparable to a good rate of responding in a population with learning disability. However, no significant differences were found between the groups on any of the dependent variables associated with the fluency tasks.

Working memory. Group differences on the spatial span task approached significance, with the group with autism tending to display relatively impaired performance: $U = 144$, $p = 0.054$; effect size $d = 0.55$. Significantly fewer people (25% versus 64%) with autism passed: x^2 $(1, N = 42) = 6.31, p < 0.05$.

Profile of executive spectrum

Results so far highlight two important, related, points. First, people with autism do not show greater impairment across all five executive domains than people with learning difficulties. Second, the absence of any group difference on three of the five domains shows the commonality in cognitive impairments between autistic and non-autistic populations.

The second aim of this research was to determine a profile of executive functioning for adults with learning disability and autism by calculating standardized composite scores for each of the executive domains (see Appendix). An overall executive functioning composite score was obtained by calculating the mean of the fluency, planning, attentional set-shifting, inhibition and working memory composite scores for each group. An independent samples *t*-test yielded no overall group effect when performance across all five domains of executive skill was considered as a whole. However, when each domain was analysed separately two significant differences emerged: working memory composite ($F(1, 38) = 8.366$, $p < 0.01$) and planning composite ($F(1, 38) = 4.79\ 1$, $p < 0.050$).

To confirm the importance of these two domains a stepwise discriminant function analysis (DFA) was performed. DFA can be used to classify cases into categories, and we used it to determine whether performance on executive tasks predicted group membership. The complex interplay between the various executive skills makes it difficult to isolate any one independently of at least one of the others. However, different tasks load more heavily (i.e. place greater demands) on certain executive skills than other tasks.

Ideally, the DFA would be performed on a randomly selected subsample of data and would then be validated on the remaining data. Given the small sample sizes involved in the present study, this was not possible; instead, all available data have been used to generate the DFA. Box's *M*-test revealed that the equality of covariance assumption was not violated (F (3, 259,920) = 0.332, p = 0.802). Thus for the DFA the individual executive functioning composite scores serve as predictor variables.

By comparing executive dysfunction in those with learning disability and autism with that in those with learning disability and no autism we were able to assess which, if any, of our predictors make a unique contribution to the profile of executive dysfunction in individuals with learning disabilities, at the same time as identifying whether any can be taken as a distinctive marker of autism rather than reflecting more generic learning disability found in populations without autism. The DFA was able to classify 75 percent of the people with autism correctly and 65 percent of the control group correctly using only the working memory and planning composites. This is significantly better than would be expected by chance alone: $x^2(2) = 11.078$, $p = 0.004$. The addition of any of the other composite scores (i.e. set-shifting, fluency and inhibition) into the DFA did not improve its ability to distinguish between the groups.

Discussion

Whilst there is an emerging consensus that a link exists between executive dysfunction and autism, many important questions remain to be answered. There is little agreement on which aspects of executive dysfunction are typical of autism across different age ranges, and which are evident at different levels of intellectual functioning. Establishing clarity on these issues is further complicated by the fact that executive dysfunction is found in clinical populations other than autism. Consequently, identifying a clinical profile of executive dysfunction in autism is problematic (Hill, 2004). However, we believe that the present findings offer a number of contributions to our understanding of this relationship, and offer an appropriate way forward.

We set out with two principal goals. The first was to conduct a detailed exploration of executive functioning in a single group of individuals with autism using an extensive test battery. The second was to obtain a profile of executive impairments in adults with autism and comorbid learning disability. We anticipated that the performance of the group with autism would be impaired on four of the five dimensions under scrutiny.

We focused on two adult populations who were closely matched on a number of dimensions to explore the relationship between executive dysfunction in adults with autism who also have learning disabilities, and executive dysfunction in adults identified as being learning disabled but not autistic. As in earlier research, we found that although executive functioning impairments were more severe and more common in the group with autism, they were not unique to this group. However, although the control group typically outperformed the group with autism, few of these differences were significant.

As expected, there were no differences between the groups on the inhibition tasks. Surprisingly, there were no significant group differences on the set-shifting (WCST) or fluency tasks either. Notwithstanding these unexpected findings, however, we were able to identify two important group differences, suggesting that a specific profile of executive dysfunction for those with autism might be possible. Discriminant function analysis revealed that planning and working memory were effective in discriminating between groups. Together, the composite scores for these domains accurately predicted group membership much better than would be expected by chance. We believe this highlights the utility and importance of employing as full a test battery as possible with a single population. The study included a number of tasks that assess a range of purported executive functioning domains. To our knowledge, no other single study has employed and considered such a broad test battery to determine a profile of executive functioning.

It is of particular interest that we find a working memory deficit. Roberts and Pennington (1996) have argued that the EF tasks that pose the greatest challenge for people with autism are those that place the heaviest demands on working memory. This might explain why the only discriminators between our two groups were the working memory and planning tasks; making as few false moves as possible on the Tower of London task demands that participants hold subgoals in mind whilst simultaneously establishing which of the possible available moves would be best (e.g. via the ‘visuospatial sketchpad’: Baddeley, 1986). An alternative account posits working memory as an attenuating factor in attentional control (Engle, 2002). More recent accounts have suggested that working memory encompasses a number of fractionated components that are responsible for inhibiting, manipulating and updating information (e.g. Belleville et al., 2003), and an association with autism has already been found (e.g. Mottron et al., 2001). Whilst a delineation of working memory processes is beyond the scope of this article, our findings support the theoretical connection between working memory and autism.

It is difficult to disentangle the effects of learning disability and autism on executive function. Indeed, it is important to consider the variability of intelligence level in autism. Intelligence ranges from profoundly learning disabled to high functioning. Most studies have focused on adults with an IQ within the normal range (i.e. between 80 and 110). An advantage of the present study was the ability to compare low-functioning adults with autism with an IQ-matched control group. However, it is important to test across the IQ spectrum and identify behaviours and characteristics which are specific to autism irrespective of IQ. Furthermore it is unlikely that a neurodevelopmental disorder affects cognition in a linear manner; therefore if we are to gain insight into the developmental pattern of executive dysfunction in autism, studies like this will need to be carried out on groups of children and adolescents. Whilst longitudinal studies of the same participants over time are difficult, a developmental picture of this area is nonetheless possible using cross-sectional findings over different age groups. Ozonoff et al. (2004) have already found evidence that planning ability remains impoverished in individuals with autism between childhood and adulthood, but improves in normally developing individuals. In contrast, set-shifting does not appear to worsen with age. Such findings suggest that extending this approach to a larger battery of tasks would be illuminating.

Our data also offer insight into the nature of executive dysfunction in learning-disabled adults who are not identifiable as having autism. There are two key suppositions regarding the intellectual impairments associated with learning disability. It may be that deficits are subserved by a universal general slowing of information processing and capacity to learn. Alternatively, learning disability may comprise a range of specific cognitive deficits, for example, in the domains of attention or memory (see Lezak, 1995). Our data seem to support the latter. Both groups demonstrated uneven profiles of performance, rather than universally impaired performance.

The present study is not without its limitations. Our sample was small, although the numbers were consistent with similar research in this area. Whilst our groups were very closely matched, in terms of both IQ measures and chronological age, our conclusions are limited to a small range of IQ. The impact of IQ on executive tasks has been extensively reported in the literature (see Hill, 2004, for an overview), and given our findings, an obvious next step would be to carry out a similar research programme across the IQ spectrum. Ozonoff et al. (2004) found an effect of IQ on planning and set-shifting in adolescents, although the mean IQ for their lower-functioning group (approximately 86) was substantially higher than that found in our current sample (approximately 68). By using similarly large batteries of executive tasks on groups within the normal IQ range, it should be possible to decide whether impairments in planning and working memory are key features across the autistic spectrum and age range.

Conclusions

Executive functioning remains a difficult construct to conceptualize. Current definitions are based upon demands and outcomes of tasks that are thought to be executive in nature, and not on a functional aetiology (Rabbitt, 1997). The majority of these tasks have been grouped into facets, or domains, of executive functioning, and their construct validity is unknown. By assessing collectively the five constructs that have received the greatest amount of attention, the present findings support the conclusion that there are differential deficits within executive functioning in an adult population with autism and learning disabilities.

One question our data do not, and cannot, answer concerns the nature of causality. It would be interesting to explore the links between executive functioning and autistic behaviour. Only a few researchers (Liss et al., 2001; Rumsey, 1985; Turner, 1997) have paid attention to this issue. For example, Turner provides an account of how impairments in the capacity to control and regulate behaviour may promote the repetitive behaviours seen in autism. We propose that the identification of the two domains of executive dysfunctioning that appear key to autism (planning and working memory) should expedite this task.

Appendix: dependent variables used to calculate the composite scores

An *a priori* decision was made that the composite scores should be derived from the dependent variables concerned with the number of correct responses made and the number of perseverative errors made, or where tests did not yield this dependent variable, the overall number of errors made. The raw scores pertaining to these dependent variables were converted into *z*-scores for each individual. In the case of error data, the polarity of the *z*-scores was inversed so that a negative value represents worse performance. The composite scores were then calculated separately for each group and for each of the executive domains by finding the mean of the *z*-scores for each domain. The score for the spatial span task (working memory) is in fact a composite score that takes into account errors and correct responses; as such this score alone was used to represent working memory, but was converted into a *z*-score in order to be comparable with the other composite scores. The dependent variables used to calculate the composite scores are shown in Table 2.

Table 2 **Dependent variables used to calculate composite scores**

	Total score	*Error score*
Attention	Map Mission: number of symbols identified	Map Mission: number of incorrect symbols identified
Fluency	Verbal fluency: mean total words Design fluency: total number of designs	Verbal fluency: mean total perseverative errors Design fluency: number of perseverative errors
Planning	Tower test: total score Mazes: total score	None Mazes: total errors
Shifting	WCST–m: number of categories completed	WCST–m: total perseverative errors
Inhibition	Knock and Tap: total correct Verbal Conflict: total correct	Knock and Tap: total errors Verbal Conflict: total errors
Working memory	Score	None

Notes

1 The accepted United Kingdom convention 'learning disability' will be used throughout this article; this is synonymous with the United States' and World Health Organization (1992) definition of 'learning disability'.

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