UNIVERSITY OF SOUTHAMPTON

Executive Function in Autism:

A Comparative Study

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July 2002

Word Count: 19396

UNIVERSITY OF SOUTHAMPTON

ABSTRACT

FACULTY OF SOCIAL SCIENCE

PSYCHOLOGY

Doctorate in Clinical Psychology

EXECUTIVE FUNCTION IN AUTISM: A COMPARATIVE STUDY

by Ben Rogers

The literature examining executive function (EF) in autism is reviewed. Current studies show that individuals who have autism demonstrate poor performance on EF measures, particularly in the area of cognitive flexibility. Theorists have suggested that EF is an underlying cognitive impairment in autism, responsible for a number of the symptoms observed in this disorder. However, the methodology used in existing research is problematic and future research is needed that examines EF in children who have autism using developmentally appropriate measures that account for the deficits observed in autism and that assess specific sub-components of EF. This study examines whether children who have autism and moderate learning disabilities perform less well than do a control group of children who have learning disabilities matched for age, verbal ability and non-verbal ability. Six EF measures were used: three existing EF measures, one modified measure and two specifically designed EF measures. Floor effects were identified for two of the measures and ceiling effects were identified for two of the measures. For the remaining two measures, results indicated no significant differences between the experimental and matched control groups on any of the EF measures used. Findings do not fit with existing empirical evidence and do not support the notion of EF as an underlying impairment in autism. However, the methodological problems identified in this study mean that conclusions are tentative in nature. Future research is required that further examines sub-components of EF in the context of autism, development and learning disabilities.

Key words: Autism; executive function; cognitive flexibility.

Acknowledgements

Firstly, my sincere thanks go to Dr. Tony Brown, who gave me the inspiration to complete a research project in this field and whose expertise in autism and learning disabilities, as well as his continual support and advice, has been invaluable in running this study. I would also like to thank Dr. Jenny Limond, for her expertise in child neuropsychology and her continual advice and support over the last year.

Secondly, my appreciation goes to all those children who were able to participate in this study and to the staff of Nettley Court School, Forest Edge School, Thornhill School and Hope Lodge School who gave me so much good support.

Thirdly, thank you to Dr. Tony Roberts for his expertise in statistics, Dr. Romola Bucks for her expertise in neuropsychology and to Tom Tutton, for his assistance in data scoring.

Finally, I would like to thank my friends and family for allowing me to be a recluse over the last few months.

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A Literature Review

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Prepared as if for submission to the Journal of Child Psychology and Psychiatry
(see Appendix 12 for instructions for authors)

Executive Function in Children who have Autism and Learning Disabilities: A Literature Review

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Executive function in autism.

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Executive Function in Autism: A Literature Review

Abstract

There exists a growing body of evidence which illustrates that individuals who have autism demonstrate poor performance on measures of executive function (EF). Indeed, theorists have suggested that EF is an underlying cognitive impairment in autism, responsible for a number of the symptoms observed in this disorder. This review considers the empirical literature examining EF in autism. EF is explored as a construct and measurement issues in adults are addressed. The developmental literature with reference to EF is examined and measurement issues investigated. Empirical research investigating EF in autism is then discussed in the context of contemporary psychological theories of autism. It is concluded that whilst studies have generally identified that individuals who have autism demonstrate greater deficits in EF than do controls, the methodology incorporated is problematic. Future research is needed that examines EF in children who have autism using developmentally appropriate measures that account for the deficits observed in autism and that assess specific sub-components of EF.

Key words: Autism; executive function; literature review.

Introduction

The term executive function (EF) describes a number of interrelated sub-skills necessary for purposeful, goal-directed activity, including volition, planning, purposeful behaviour and effective performance (Lezak, 1995). Researchers have noted that a number of the key features of autism are reminiscent of the EF deficits that follow frontal lobe injury such as rigid, inflexible, perseverative and impulsive behaviour (Ozonoff, 1995a). There is now growing evidence that deficits in EF may be of importance to our understanding of the autistic syndrome (Turner, 1997) and EF has been highlighted as an underlying cognitive impairment relating to other models of autism: theory of mind (Russell, 1997), emotion perception (Ozonoff, Pennington & Rogers, 1991), imitation (Rogers & Pennington, 1991), pretend play (Harris, 1993) and repetitive behaviour (Turner, 1997).

This review is separated into two main sections. The primary sector examines current research in EF, including neurological underpinning, developmental processes and measurement issues. It is concluded that within the literature there is a need for greater specificity in the definition and measurement of EF (Pennington & Ozonoff, 1996) and that greater emphasis is required on EF in the context of development including measures appropriate for child populations (Anderson, 1998). The second sector examines EF in the context of autism, presenting psychological theory and existing empirical findings within this field. It is concluded that existing studies suffer a number of significant empirical problems that question the validity of EF as an underlying impairment in autism. It is concluded that further research is required that focuses on developing measures that are sensitive to deficits observed in autism and learning disabilities.

Executive Function

The definition and measurement of EF is a necessarily complex sphere of research within the field of psychology. In providing an understanding of EF deficits in autism, this paper first presents a conceptual understanding of EF and briefly explores neurological underpinnings and measurement techniques used within this field. It then describes developmental issues in EF and explores the measurement of EF in children.

Defining Executive Function

EF is described as an umbrella term, encompassing a number of interrelated sub-skills necessary for purposeful, goal-directed activity (Lezak, 1995; Stuss & Benson, 1986), sometimes described as maintaining an appropriate problem-solving framework (Bailey, Phillips & Rutter, 1996). Lezak (1995) proposes four key components of EF: volition, planning, purposeful behaviour and effective performance, each of which involves further sub-components. As well as these core components, qualitative impairments are also identified in individuals who demonstrate EF deficits including poor self control and erratic careless responses (Lezak, 1995). A key linking feature of all EFs is that they are goal-directed and future-oriented (Welsh & Pennington, 1988; Welsh, 2002) and all involve the ability to disengage from the immediate environment and/or external context and guide behaviour instead by mental models or internal representations (Dennis, 1991).

To further complicate this field, it has been suggested that such EFs are only used within novel situations, not well-learned behavioural patterns (Shallice, 1990). Indeed, EF is described as the most complex aspect of an individual's cognitive capacities, due to the variety of functions required to select, plan, organise and implement a behavioural response appropriate to a constantly changing world (Sparrow & Davis, 2000). Whilst the domain of EF is distinct from cognitive domains such as sensation, perception, and aspects of language and memory, it overlaps with domains such as attention, reasoning and problem-solving, but not perfectly (Pennington & Ozonoff, 1996). However, it should be recognised that in the assessment of EF, individuals may require adequate memory, attention and language skills to be able to understand, recall and focus on a task. Although certain researchers have identified a role for working memory within EF (e.g. Baddeley, 1986) this is not specified within Lezak's definition and will therefore not be explored within this paper.

Pennington et al (1997) concluded that the term 'executive function' is widely used to refer to the cognitive processes involved in the planning and execution of complex behaviour, without necessarily specifying what those processes are more precisely. This position lacks theoretical precision and makes comparison of studies examining EF problematic, suggesting a need for greater specificity within the literature. However, despite limitations, the construct of EF is described as having both utility and evidence of convergent and divergent validity (Pennington & Ozonoff, 1996).

Neurological Function and Executive Function

EFs have traditionally been thought to be mediated by frontal lobe function since damage to this region results in a classic pattern of behavioural and cognitive abnormalities, including EF deficits (Stuss & Benson, 1986). Moreover, on parallel descriptive levels, developments in EF mimic the curve of frontal connectivity (Thatcher, 1991). The frontal lobes constitute more than one third of the brain's total size (Wilson & Powell, 1994) and are made up of the precentral, premotor and prefrontal areas (Lezak, 1995). Whilst the precental and premotor areas relate to physical movements, the prefrontal cortex (PFC) relates to 'higher order' functions. Hodges (1994) suggested two categories of PFC function: adaptive behaviour and EF, which together comprise sub-categories of abstract conceptual ability including set shifting (mental flexibility), problem-solving, planning, initiation, sequencing of behaviour, temporal-order judgement, personality and social behaviour. Indeed, most patients who have significant damage of the prefrontal regions, particularly when orbital or medial structures are involved, experience behavioural and personality changes stemming from defective EF (Lezak, 1995). Research investigating PFC function and EF has led to the term '*frontal lobe syndrome*', which is generally used to refer to a varied group of behaviours that result from a diverse range of aetiologies, with varying locations and extent of neurological abnormality (Stuss & Benson, 1984).

From this limited theoretical history and despite evidence suggesting that EFs are also sensitive to damage in other areas of the brain (Stuss & Benson, 1984), the term EF has become synonymous with frontal (or more correctly, prefontal) lobe functions (Denckla, 1996). It has been argued that specification of the syndrome in terms of localization is potentially misleading (Baddeley & Wilson, 1988) and that EF may be interpreted as a purely psychological concept, relating to a set of observable behaviours, without reference to anatomical underpinnings. In an attempt to move away from anatomical explanations of executive problems, Baddeley (1986) suggests the term '*dysexecutive syndrome*' as a functional characterisation of patients with this particular pattern of deficits.

Measurement of Executive Function

A wide range of neuropsychological measures have been developed for the functional assessment of EF. Table 1 illustrates some commonly administered measures.

Insert table 1 about here

Despite their wide use in studies as well as in clinical practice, a number of EF assessment measures suffer from four key problems identified by Pennington and Ozonoff (1996): 1) they are not well defined, 2) they do not allow the identification of component processes, 3) they are not always reliable and normally distributed, and 4) they do not appear to be sensitive to the same underlying processes across a range of performance. Pennington and Ozonoff (1996) suggested that measures such as the Wisconsin Card Sorting Test (WCST) or the Tower of Hanoi tap multiple functions as well as nonexecutive components. This makes differentiation of EF components and also comparison between clinical groups difficult, since two groups might obtain the same score on a test, but have deficits in different components of EF. They argue that such tests involve social processing and specific knowledge (e.g. number and colour) and suffer from sensitivity and ceiling problems. Despite criticism of existing measures, such tests are still commonly used as indicators of EF deficits. Contemporary neuropsychology would argue that this approach is too simplistic and that it is critical to carefully evaluate assessment tools, considering the specific components of EF that they measure (Anderson, 1998).

In the application of neuropsychological measures assessing EF, three key areas of difficulty are apparent within the literature (Denckla, 1996): general intelligence, the integrity of cognitive processes and the mediating role of language. Primarily, there is the need to separate executive skills from general intelligence, in that a high intelligence quotient (IQ) may make certain measures of EF too easy to be sensitive to an individual's executive skills (Denckla, 1996). Despite findings of impaired EFs such as planning, flexibility of thought and judgement without major change in IQ (Kolb & Wishaw, 1995) certain tests such as the Wisconsin Card Sorting Test-Categories Achieved (WCST-CA: Heaton, 1981) may correlate with Verbal IQ (VIQ: Reader, Harris, Schuerholz & Denckla, 1994) suggesting a need for tests that are matched to the ability level of the individual. Secondly, Tranel, Anderson and Benton (1995) identified that individuals who have sustained nonfrontal lesions that damage perception, memory or language abilities, fail the WCST. Measures of EF should therefore use only intact content domains. Thus, if a measure requires an individual to read, their reading level should be consistent with their IQ. A final difficulty identified by Denckla (1996) is that language ability may play a mediating role in those EF tasks that utilise a verbally stated rule or verbally stated constraints, in that verbally mediated rules may dominate much of working memory for most people. Thus, traditional measures of EF may be criticised on a number of levels as well as in their application.

Executive Function in Children

Developmental psychologists agree that behaviours associated with EF such as planning, flexibility and self monitoring are evident throughout the life span (Welsh & Pennington, 1988). Indeed, executive function has been successfully assessed in infants (Espy & Kaufmann, 2002) and in typically developing children (Kelly, 2000). It is thought that EFs develop in a stage-like manner, consistent with growth spurts observed in the central nervous system (Anderson, 1998). Evidence suggests that key stages in EF development occur during middle childhood and later at adolescence (Anderson, Anderson & Lajoie, 1996; Becker, Isaac & Hynd, 1987; Passler, Isaac & Hynd, 1985; Kelly, 2000; Levin et al. 1991; Welsh, Pennington & Groisser, 1991). However, studies have not examined EF using consistent definition or measures and whilst it is thought that development occurs in parallel to development of the fontal lobes, development in other cerebral areas needs to be considered as well as the emergence of memory, language and processing abilities (Anderson, 1998). Moreover, it is argued that there is a need for deficits to be assessed in comparison to normative developmental ability, rather than adult ability (Welsh & Pennington, 1988).

A critical difficulty in interpreting existing studies of EF in children is that the development of EF in childhood has been studied using two independent conceptual frameworks. The clinical neuropsychological approach (e.g. Levin et al. 1991) suggests a multi-component model of executive function as described above, whereas the developmental neuropsychological approach argues for a unitary explanation of EF based on a working memory model (Kelly, 2000). Using the WCST, Tower of Hanoi, the Matching Familiar Figures Test, visual search, verbal fluency and motor sequencing tests with 100 typically developing children, Welsh et al (1991) identified three developmental trajectories of EF (6, 10 and 13 years). Adult-level competence varied by task and a factor analysis illustrated three separate EF factors: speeded response, set maintenance and planning, suggesting a multi-component model of EF (Welsh et al. 1991).

Despite significant methodological difficulties in research, deficits in EF have been identified in a number of childhood disorders including autism (e.g. Ozonoff & McEnvoy, 1994) and attention deficit hyperactivity disorder (e.g. Shue & Douglas, 1992). The goal of neuropsychological studies examining developmental disorders is to identify the primary neurocognitive deficit in each disorder. Indeed, review of the literature suggests that the severity and profile of EF deficits appears to differ across developmental disorders (Pennington & Ozonoff, 1996).

Measurement of Executive Function in Children

In considering the assessment of EF in children, researchers (e.g. Anderson, 1998; Pennington & Ozonoff, 1996; Welsh et al. 1991) have argued that accurate and reliable identification of EF deficits, in both clinical practice and research, continues to be limited due to a lack of developmentally appropriate assessment measures. It is suggested that most available tests have been developed for use with adults and their inclusion in assessment is based on the assumption that they will detect similar dysfunction.

Standardised assessment batteries used with children, such as the Wechsler Intelligence Scale for Children- III (WISC-III: Wechsler, 1991) or the Luria-Nebraska Neuropsychological Battery (Golden, 1986), show a lack of focus on measures of executive function. However, the NEPSY (Korkman, Kirk & Kemp, 1998), a more recent battery, incorporates an EF subscale using four independent measures (the tower task, the statue task, design fluency and the knock and tap task) illustrating the increasing recognition of EF as a measurable developmental neuropsychological feature. It should however, be recognised that factor analysis has not yet provided conclusive evidence of an independent EF sub-component of this battery (Korkman, et al. 1998). Stinnett, Stinnett, Fuqua & Palmer (2002) suggested that although the NEPSY subtests show adequate specificity, further research examining the utility of the NEPSY is required and practitioners should be cautious in interpreting results taken from the core domain and subtest profiles of children's performance.

In addition to standardised assessment batteries, individual assessment measures that use standardised administration procedures are available with some child normative data, including the Complex Figure of Rey, Tower of London/Hanoi, Controlled Oral Word Association, WCST, Trail Making Test, and Stroop Test (Anderson, 1998). However, these measures are typically derived from adult tests, sometimes with the use of child instructions (e.g. Golden, 1978) and may not be adequately validated or normed, making interpretation of existing studies problematic (Anderson, 1998). Indeed, it is not only the use of adult tasks with children that is problematic, as tasks developed for older children may not actually tap the same functions when used with younger children (Klinger & Renner, 2000).

Conclusions

It is clear from the literature that obtaining a clear definition of EF is problematic. Pennington and Ozonoff (1996) concluded that whilst the definition of EF is both provisional and under-specified, the construct of EF has some utility and validity. In theoretically integrating models of cognition and intelligence, Sparrow and Davis (2000) argued that to fully understand comprehensive cognitive functioning, one must comprehend the performance of the individual components as well as their integrated or gestalt functioning, suggesting a need for specificity. The need for greater specificity is supported within the literature (e.g. Pennington et al. 1997).

Evidence from research investigating EF in children suggests that EFs are both evident throughout childhood (Welsh & Pennington, 1988) and develop in stages during middle childhood and adolescence (e.g. Welsh et al. 1991). However, methodological difficulties associated with the application of EF measures in child populations suggests a need for tests that are both designed for children, taking development into account and applied sensitively with their needs in mind (Anderson, 1998).

Executive Function and Autism

Autism is a well researched field within developmental psychology and clinical child psychology. However, despite this research little is known about the cause and development of this neurodevelopmental disorder. In linking the fields of EF and autism, this paper explores current psychological theory in autism. Studies exploring EF in autism are reviewed and relative strengths and weaknesses of empirical evidence are highlighted. Findings are then related back to the underpinning psychological theory.

The Diagnostic Criteria of Autism

Despite over fifty years of research investigating autism, with developing evidence suggesting a genetic basis (Rutter, Bailey, Bolton & Le Couteur, 1993), its precise cause remains a mystery (Klinger & Dawson, 1996). However, despite this uncertainty about the origins of autism, clinicians and researchers have achieved some consensus on the validity of autism as a diagnostic category and on the many features central to its definition (Rutter, 1999). Current diagnostic criteria for autism are typically discussed with reference to two independent, though interlinked systems: DSM-IV (American Psychiatric Association:APA, 1994) and ICD-10 (World Health Organisation: WHO, 1992) diagnostic criteria. Autism is a behavioural syndrome, defined by a cluster of behaviours (Romanczyk, Lockshin & Navalta, 1994) and both diagnostic systems use the three core-defining features of autism as the basis for diagnosis: impairments in socialisation, impairments in verbal and nonverbal communication and restricted and repetitive patterns of behaviours. In addition to this triad of impairments, both systems specify that the child should have abnormal or impaired development before the age of 3 years in at least one of the following areas: social interaction, language and symbolic or imaginative play. Moreover, in making a differential diagnosis, autistic disorder must be distinguished from other forms of pervasive developmental disorder (Schreibman & Charlop-Christy, 1998). The importance of diagnosis is well recognised within the literature since early diagnosis and subsequent intervention improves the prognosis for children who have autism (Freeman, 1997).

Psychological Theories of Autism

It has been argued that in order to develop a comprehensive understanding of a developmental psychopathology, a shift is required from descriptive accounts to causal processes and underlying mechanisms (Rutter, 1988). Despite relatively accurate diagnostic descriptions of autism, psychological understanding of underlying impairments is less comprehensive (Ozonoff, 1995a). The theoretical basis of autism within psychology focuses on three distinct, though interconnected theories: Theory of Mind, Central Coherence and Executive Function.

Arguably the most prominent psychological theory of autism is that individuals who have autism lack 'theory of mind'(Baron-Cohen, Leslie & Frith, 1985, 1986), a cognitive mechanism that should come on-line in the second year of life in typically developing children (Leslie, 1987). Essentially, theory of mind involves the child postulating the experience of mental states and then using these to explain and predict another person's behaviour (Baron-Cohen, 1989) and has been implicated as an underlying cognitive impairment in autism, producing deficits in social ability (Frith, 1989), communication (Happe, 1993), imagination (Lillard, 1993) and repetitive and restricted behaviours (Baron-Cohen, 1989). However, research has identified that certain high-functioning verbal autistic children and adolescents are able to pass theory of mind tasks to the same level as controls (e.g. Bowler, 1992). Since it might be expected that the fundamental underlying deficit of autism would be present among all individuals who have autism, these findings cast doubt over the explanatory power of the theory of mind hypothesis (Ozonoff, 1995a).

An alternative psychological theory, though less researched, focussing on perception, is that an underlying problem in autism is a weak drive for central coherence (Frith, 1989). Frith describes central coherence as the ability to draw together diverse information to construct higher-level meaning in context. Thus, rather than making sense of the global features of a situation, individuals who have autism perceive the world in a piecemeal way (Frith & Happe, 1994), perceiving the detail rather than the whole gestalt. Weak central coherence has been used to explain the deficits observed in autism in relation to the processing of part-whole relationships (Frith, 1989).

In contrast to the narrow focus of theory of mind or central coherence, is the broader psychological theory (Bailey et al. 1996) that individuals who have autism demonstrate deficits in EF (e.g. Hughes, Russell & Robbins, 1994; McEnvoy, Rogers and Pennington, 1993). EF has been highlighted as an underlying cognitive impairment in theory of mind (Russell, 1997), emotion perception (Ozonoff, Pennington & Rogers, 1991), imitation (Rogers and Pennignton ,1991), pretend play (Harris, 1993) and repetitive behaviour (Turner, 1997).

It is argued that the utility of psychological theories of autism depends on the extent to which each can account for the triad of impairments observed in autism (Bailey, Philips & Rutter, 1996). Whilst each theory can account for at least some of the impairments and skills observed in autism, theory of mind (e.g. social problems), central coherence (e.g. idiot savant skills) and executive function (e.g. repetitive and stereotyped behaviour) none in isolation can account for the behavioural phenotype (Rutter, 1999). Indeed, Bailey et al (1996) argued that psychology may require several specific cognitive deficits to explain the range of features observed in autism, suggesting a need for a greater integration of psychological theories of autism.

Cognitive Functioning in Autism

Although it has traditionally been assumed that approximately 75 per cent of children who have autism have IQs below 70 (Rutter, 1979), a recent population study (Baird, 2000) cited in the Medical Research Council's (2001) review of autism research, suggested that this figure may be closer to 25 per cent. Moreover, it has been suggested that an IQ of above 50 (especially verbal IQ), is a particularly significant protective factor associated with a better prognosis (Carr, 1999) and that intellectual abilities in autism appear to be stable after five years of age and are predictive of later academic and work achievement (DeMeyer et al. 1974). Assessing cognitive functioning is critical when trying to establish a discrepancy between the child's level of social function and the overall cognitive and adaptive function, a key criterion in the diagnosis of autism; and will provide important information for planning intervention and evaluating its effects (Filipek et al. 1999).

In assessing IQ in children who have autism, the WISC-III (Wechsler, 1991) is recommended for higher functioning individuals (Filipek et al. 1999). It has been identified that individuals who have autism often demonstrate higher Performance Quotients (PIQ) than Verbal Quotients (VIQ) (Lincoln, Allen & Killman, 1995). However, this discrepancy can be misleading since when Full Scale Quotients (FSIQ) and VIQ are above 70, individuals do not show this discrepancy (Siegel, Minshew & Goldstein, 1996). However, in assessing those individuals who are lower functioning or non-verbal, it is recommended that tests be used which: are age appropriate (mental and chronological); provide a full range of standard scores; assess both verbal and non-verbal skills; provide an overall index of ability and have norms which are current and relatively independent of social function (Filipek et al. 1999).

Executive Function as an Underlying Impairment in Autism

It is critical within this field to examine the extent to which EF fits with our current theoretical understanding of autism. Ozonoff (1995a) argued that a number of the key features of autism are reminiscent of the EF deficits that follow frontal lobe injury. For example, the behaviour of individuals who have autism is often rigid, inflexible, perseverative and impulsive, with individuals seemingly able to possess large stores of information but not able to use it correctly. Moreover, the growing evidence for EF deficits in autism has led to the suggestion that deficits in EF may be of primary importance to the autistic syndrome (Turner, 1997). As has been commented, EF has been highlighted as an underlying cognitive impairment in theory of mind (Russell, 1997), emotion perception (Ozonoff, Pennington & Rogers, 1991), imitation (Rogers & Pennignton, 1991), pretend play (Harris, 1993) and repetitive behaviour (Turner, 1997).

However, in order to evaluate a possible causal role for EF in the development of autism, Turner (1997) argued that three predictions must be fulfilled: firstly that any such deficit is universal to autism; secondly, that it is autism specific; and thirdly, that any variance in the severity of EF will be associated with variance in the degree of autistic features.

Table 2 illustrates studies identified as examining executive function in autism. Data are taken from existing reviews (e.g. Penington & Ozzonoff, 1996; Ozonoff, 1995a) and papers identified through extensive literature review. Inclusion criteria were that studies used EF measures, a control group and were published in a peer-reviewed journal.

Insert table 2 about here

Strengths of Empirical Evidence

The clinical and theoretical importance of this field of research has led to a relatively large number of empirical studies in what is a developing field. Twenty-five studies were identified that matched the specified inclusion criteria and are included in Table 2. All studies used control groups, existing EF measures and statistical analyses.

Preliminary studies of EF in individuals who have autism, using single-case methodology, and existing neuropsychological measures such as the WCST, identified perseverative responses and the use of rigid and inflexible problem-solving strategies (Steel, Gorman & Flexman, 1984). Early empirical studies using multiple participants and control groups (e.g. Rumsey, 1985; Rumsey & Hamburger, 1988; Szatmari, Tuff, Finlayson & Bartolucci, 1990; Rumsey & Hamburger, 1990) corroborated these findings, suggesting that individuals with autism demonstrate impaired performance on the WCST when compared to matched controls, particularly in perseverative errors. Prior and Hoffman (1990) developed an adapted version of the WCST, omitting all ambiguous cards and providing explicit instructions about when to shift set. Even using this simplified version, children with autism performed less well than did controls. Later studies, using the WCST, supported these early findings (Szatmari et al. 1990; Ozonoff et al. 1991; Ozonoff, Rogers, Farnham & Pennington, 1993; Ozonoff & McEnvoy, 1994; Ozonoff, 1995b; Bennetto, Pennington & Rogers, 1996; Ozonoff & Jensen, 1999; Goldstein, Johnson & Minshew, 2001; Liss et al. 2001; Shu, Lung, Tien & Chen, 2001) particularly with reference to perseverative errors. However, although a large number of studies have identified significant differences between autistic and control participants using the WCST, not all studies find this difference. Schneider and Asarnow (1987) and Minshew, Goldstein, Muenz and Payton (1992) both identified non-significant differences using the WCST.

The findings presented above, when taken together, suggest that performance on the WCST is generally, though not always, impaired in individuals who have autism, particularly in perseverative errors and responses. Such findings have led researchers to develop theories about the 'profile' of EF deficits in autism. In reviewing current EF literature with respect to different developmental psychopathologies, Pennington and Ozonoff (1996) argued that existing empirical evidence illustrates a significant deficit in cognitive flexibility.

Despite the relative dependency on research using the WCST, a number of studies have attempted to use further measures of EF. Individuals with autism have been found to show impaired EF abilities when tested using the Word Fluency test (Rumsey & Hamburger, 1990), the TOH/TOL (Ozonoff et al. 1991; Hughes et al. 1994; Ozonoff & McEnvoy, 1994; Bennetto et al. 1996; Ozonoff & Jensen, 1999), Trails A (Minshew et al. 1992; Goldstein et al. 2001), Trails B (Rumsey & Hamburger, 1988, Goldstein et al. 2001), Mazes (time) (Prior & Hoffmann, 1990) Rey-Osterreith Complex Figure (Minshew et al. 1992), Windows, Detour Reach (Hughes & Russell, 1993), Intra-dimensional/ Extra-dimensional set shifting task (ID/ED: Hughes et al. 1994), Go-no-Go (Ozonoff, Strayer, McMahon & Filloux, 1994), Temporal Order (words and pictures) (Bennetto et al. 1996), and the Stroop test (Goldstein et al. 2001). Thus, EF deficits are also observed in measures other than the WCST. The results illustrated identify that both children and adults who have autism perform less well than do controls, on a variety of measures of executive function. Such findings provide strong support for EF as a significant deficit in autism.

A final strength of existing studies is the development of computerised tests of EF. For individuals who demonstrate social avoidance (as is observed in autism), the elimination of social interaction in computerised tests may aid performance (Ozonoff, 1995b). Indeed, Ozonoff (1995b) demonstrated that when using a computerised version of the WCST, individuals who have autism performed at the same level as did controls, although when using the standard version, these participants did significantly worse than did controls, suggesting that the standard version of the WCST may not be easily accessible to children who have autism. However, Hughes et al (1994), using computerised versions of the ID-ED task and the TOL planning task, identified that children who have autism performed significantly worse than did matched controls. Both studies highlight empirical possibilities for using computerised tests for children who have autism.

Limitations of Empirical Evidence

Despite criticism within the literature of the WCST as a valid measure of EF, 17 of the 25 studies examined used the WCST as a primary measure of EF. Other tests included the TOL, TOH, Complex Figure of Rey, and Stroop Test. In light of Pennington and Ozonoff's (1996) suggestion that measures such as the WCST and the TOH tap multiple functions as well as nonexecutive components, it would seem that few of the studies show any specificity of measures. Moreover, Ozonoff (1995b) identified that whilst children who have autism performed worse than did controls using a traditional version of the WCST, using a computerised version, group differences were non-significant. This not only suggests that the traditional WCST may be an inappropriate measure for children who have autism, but also highlights the need for newly designed measures within this field.

As highlighted above, although a large number of studies have identified significant differences between autistic and control participants using the WCST, not all studies have identified this difference (e.g. Schnieder & Asarnow, 1987; Minshew et al. 1992). In addition, studies have failed to find differences between autistic and control groups on the following measures: Stroop (Eskes, Bryson & McCormick, 1990, Ozonoff & Jensen, 1999), Modified Stroop (Russell, Jarrold & Hood, 1999), Trails B (Minshew et al. 1992), A not B task (McEnvoy et al. 1993; Griffith, Pennington, Wehmer & Rogers, 1999) Alternation task (McEnvoy et al. 1993), TOH (Ozonoff et al. 1993), Rey-Osterrieth (Minshew, Goldstein & Siegel, 1997), working memory sentence span, working memory counting span (Bennetto et al. 1996), object retrieval, A not B with invisible displacement, 3-boxes, 6 boxes, spatial reversal (Griffith et al. 1999) underlining test, and rapid automatized naming (Shu et al. 2001). These findings strongly refute the EF theory of autism, since it should be expected that EF deficits are universal to all individuals who have autism (Turner, 1997).

All studies examined in this review have used control groups. However, the methodology employed in matching and selection of participants is somewhat inconsistent. Of primary consideration is the need for ability-matched groups, since it has been argued that there is a correlation between measures such as the WCST and VIQ (Reader et al. 1994). The discrepancy between VIQ and PIQ observed in autism (Lincoln et al. 1995) suggests the need for measures that tap both domains. Of the 25 studies examined, only 12 are matched for VIQ and PIQ. Secondly, despite autism being more common in males, in a ratio of about 4:1 (Gillberg & Coleman, 1992), only 14 of the 25 studies specify gender matching. A final issue is the use of other clinical groups such as ADHD, dyslexia and borderline LD in control groups (e.g. Bennetto et al. 1996). Given the finding that other groups (e.g. ADHD) may demonstrate deficits in EF (Pennington & Ozonoff, 1996) using control groups in this way may affect results.

Recent empirical findings suggest that approximately 25 per cent of individuals who have autism have IQs below 70 (Baird. 2000). However, of the 25 studies examined in this review, 20 examined high functioning autism (HFA) whilst only 3 examined learning disabilities (LD) specifically. One study also examined both HFA and LD and one examined ‘developmental delay’ but did not specify whether children had a diagnosis of LD. As such, with only three studies examining individuals with autism who have learning disabilities, there may be a need for further examination of the nature of EF deficits in individuals who have autism and learning disabilities.

Despite the critical importance of taking developmental issues into consideration when considering EF (Welsh & Pennington, 1988), of the 25 studies identified examining EF in autism, 9 used mixed populations of children and adults, 3 were conducted using adult populations and 13 using child populations. If it is accepted that there exist developmental trajectories of EF as suggested by Welsh et al (1991), the findings of studies including both children and adults are called into question. Moreover, the relative dependency of child studies on traditional EF measures such as the WCST (8 of the 13 child studies used this measure) is problematic (Anderson, 1998).

More difficult to assess than development and ability is to what extent studies account for the deficits observed in autism (e.g. social and communication problems, theory of mind deficits and deficits in central coherence) and have used or developed measures and procedures that account for these deficits. For example, children who have autism are known to perform better than control participants matched for mental age on the Block Design subtest of the Wechsler Intelligence Scales (Wechsler, 1981) than would typically be predicted by developmental level, which has been explained in terms of central coherence (Shah & Frith, 1993). It is possible that existing measures tap into skills or deficits in this way and so affect findings. However, little discussion is given to this issue within the literature with the exception of computerised measures (Ozonoff, 1995b; Hughes, Russell & Robbins, 1994).

Relating Empirical Evidence of Executive Function to Psychological Theories of Autism

In evaluating existing empirical evidence in the context of current psychological theory, Turner's (1997) criteria for the evaluation of a possible causal role for EF in the development of autism may be applied.

In relation to the first criterion, that a deficit in EF should be universal to autism, the majority of studies have identified significant differences between autistic and control participants using measures of EF (e.g. Ozonoff et al. 1993; Rumsey & Hamburger, 1990; Szatmari, 1990) suggesting that such deficits may be universal if measured appropriately. Moreover, in their study, Ozonoff et al (1991) compared the same participants on EF and theory of mind measures, identifying that deficits in EF tasks were more common than were deficits in theory of mind tasks. In attempting to evaluate the extent to which EF can be said to be universal to autism, Bailey et al (1996) suggested that this study provides superficial evidence supporting the candidature of EF as a primary cognitive deficit in autism. However, not all studies have consistently identified EF deficits in individuals who have autism, a small number of studies identifying similar levels of EF deficit in both autistic and control samples (e.g. Schnieder & Asarnow, 1987; McEnvoy et al. 1993; Minshew et al. 1997) thus refuting such a theory.

In relation to the second criterion, that deficits in EF should be specific to autism, individuals with disorders other than autism show deficits in EF. In a review of existing studies in this field, Pennington and Ozonoff (1996) identified that EF deficits have been consistently identified in autism and ADHD. However, they argued that whilst EF deficits have been observed in autism and ADHD, the nature of these difficulties differs between the two psychopathologies. They reported that in autism, deficits in cognitive flexibility were consistently identified across the literature using measures such as the WCST (e.g. Bennetto et al, 1996; Ozonoff & McEnvoy, 1994). Conversely, they suggested that in ADHD, deficits were not typically identified using the WCST (e.g. Weyandt & Willis, 1994) but were consistently identified using measures of motor inhibition such as the Go No-Go task (e.g. Shue & Douglas, 1992). In addition, Pennigton and Ozonoff (1996) illustrated that research using measures such as the WCST and Go No-Go task has not shown EF deficits in Tourette Syndrome (e.g. Ozonoff et al. 1994; Sutherland, Kolb, Scoel, Whishaw & Davies, 1982) and that research using measures such as the WCST and has not shown deficits in Conduct Disorder (e.g. Moffitt & Henry, 1989). They have used this evidence to suggest that 'profiles' of EF deficit are observable across developmental psychopathologies, in that studies have shown different EF deficits in the different disorders. Although profiles are provided for both autism and ADHD, further psychopathologies are not examined to assess the degree to which these profiles are psychopathology specific (i.e. are not identified in other developmental psychopathologies). As such, one cannot say that a specific profile is completely unique to each disorder. Moreover, Pennington and Ozonoff (1996) suggested that further research using discrete EF measures is necessary to confirm these indications of profile differences between disorders. Such findings suggest that global EF deficits are not specific to autism. Instead, it would seem that specific profiles of EF deficits may be unique to each disorder.

In relation to Turner's (1997) third criterion, that any variance in the variability of EF deficit will be associated with variability and severity of the autistic symptomatology that is suggested to stem from this deficit, few studies examine this issue in any depth. However, Ozonoff et al (1991) identified a positive correlation between EF deficits and theory of mind deficits, suggesting that variance in the variability and severity of EF is associated with variability and severity of deficits in theory of mind.

Conclusions

Psychological theories of autism have sought to explain the behavioural symptoms observed in individuals who have autism in terms of an underlying cognitive impairment. Three primary theories have been presented: theory of mind, central coherence and EF. EF is able to provide a theoretical explanation for a number of the key features of autism, such as rigid, inflexible, perseverative and impulsive behaviour (Ozonoff, 1995a). Indeed, it has been highlighted as an underlying cognitive impairment with respect to a number of features of autism (e.g. Ozonoff et al. 1991; Rogers & Pennington, 1991; Turner, 1997).

The majority of current empirical evidence suggests that individuals who have autism perform less well on measures of EF than do matched controls (e.g. Ozonoff et al. 1991; Bennetto, et al. 1996; Goldstein et al. 2001). However, a small number of studies have failed to identify significant differences between autistic and control participants using certain measures (e,g, Minshew et al. 1992; Ozonoff & Jensen, 1999). Many existing studies rely on global measures of EF such as the WCST, matching criteria in studies is inconsistent and few include any discussion of the measurement of EF in the context of autism-specific impairments. Moreover, in relating empirical research to psychological theory, not all studies provide convincing evidence for EF as the underlying impairment in autism. The contradictory findings highlighted, in conjunction with empirical issues of measurement and matching suggest the need for further research to be conducted within this field.

Future Research

To properly identify possible EF deficits in autism, and to subsequently assess the nature of EF as an underlying cognitive impairment in autism, future research must carefully consider a number of critical issues.

A primary criticism of existing studies of EF is the use of global measures of EF such as the WCST and the TOH that may tap multiple EFs and other cognitive functions. It is argued that future research using discrete EF measures, assessing sub-components of EF is required in order to more accurately identify the exact nature of EF deficits in autism (Pennington & Ozonoff, 1996), breaking down components into sub-components of EF and examining the nature of such sub-components, thus manipulating only one specific skill (Griffith et al. 1999). The development of molar EF measures that are able to accurately assess sub-components of EF would allow clinicians and researchers to measure profiles of EF in individuals (Pennington & Ozonoff, 1996). Such cognitive profiles would not only assist researchers in understanding the development of EF in autism, but could also be used in performance-based measures used in diagnosis and assessment in autism (Klinger & Renner, 2000). Moreover, measures of this type would allow for a more accurate empirical validation of the importance of EF as an underlying impairment in autism as suggested by Turner (1997), since these measures would allow the nature, specificity and variability of EF in autism to be more closely assessed. As has been highlighted, when compared to children who have ADHD, Conduct Disorder and Tourette Syndrome, children who have autism show marked deficits in cognitive flexibility, a sub-component of EF (Pennington & Ozonoff, 1996). Future research investigating the exact nature of cognitive flexibility might therefore aim to identify and/or develop measures of EF that examine this sub-component in greater detail.

Despite the empirical finding cited in the Medical Research Council's (2001) review of autism research, that approximately 25 per cent of individuals who have autism have IQs below 70 (Baird, 2000), the vast majority of studies examining EF in autism examine high functioning individuals. It is therefore necessary to show that impairments in EF are also apparent in the larger population of less able individuals (Hughes et al. 1994). However, in existing studies examining individuals who have learning disabilities, many use the same tests that are used within typically developing child populations (e.g. Russell et al. 1999). Whilst certain EF measures are said to be applicable for individuals who have learning disabilities (Hughes et al. 1994) greater efforts should be made to examine the extent to which EF measures tap general intelligence as well as EF. Moreover, further research is required which examines the nature of EF deficits in individuals who have autism and learning disabilities to understand if such deficits are the same or different to those observed in high functioning individuals.

It has been suggested that accurate and reliable identification of EF deficits, in both clinical practice and research, continues to be limited due to a lack of developmentally appropriate assessment measures. Most available tests have been developed for use with adults and their inclusion in assessment is based on the assumption that they will detect similar dysfunction in children (e.g. Anderson, 1998; Pennington & Ozonoff, 1996; Welsh et al. 1991). Indeed, few child EF measures are adequately validated or normed, making interpretation of existing studies problematic (Anderson, 1998) and tasks developed for older children may not actually tap the same functions when used with younger children (Klinger & Renner, 2000). Thus, there is a clear need for further measures that are sensitive to developmental level and that also engage children using fun, motivating tasks. It is acknowledged that adapting existing measures may distort these measures. As such, there is a need to examine whether adapted or new measures are assessing the same thing as existing measures. One way to assess such changes might be to test a normative sample of children using the existing and newly developed measures and examine performance on both measures (i.e. using correlational analyses). This would show whether performance on the measure is affected by including motivating tasks. If new, fun measures are tapping the same EF as existing measures, using them may be a less stressful alternative for children.

There now exists a comprehensive and ever-developing literature examining the deficits observed in autism and the need for careful assessment of such deficits (e.g. Bailey et al. 1996). In line with this theory exists a parallel literature examining underlying cognitive impairments that might be responsible for such deficits (e.g. Russell, 1997). However, in studies examining the prevalence of EF deficits in autism, few have discussed the importance of identifying measures that assess EF in isolation to the behavioural impairments observed in autism. For example, Ozonoff (1995b) and Hughes et al (1994) both discussed the relevance of using computerised measures with children who have autism, since such children are anecdotally reported to interact well with computers (which may be due to the removal of a social interaction with another person). Thus, further EF measures should be developed that account for the triad of impairments, using minimal verbal communication and human interaction and that are not influenced by repetitive behaviours. Moreover, measures should not be affected by deficits in theory of mind, central coherence or sensory difficulties. A further goal of future research should then be to examine how performance in children who have autism might differ on existing EF measures and those that do not depend on areas of deficit observed in autism (e.g. communication and language deficits and repetitive behaviours).

Despite an existing literature examining rehabilitation of EF in individuals who have suffered head injuries (e.g. Levine et al. 2000), the literature reviewed with reference to autism makes no recommendations about the development of treatment protocols for EF deficits observed in autism. Given that it is acknowledged that early intervention is critical in autism (e.g. Howlin, 1998) future research is urgently required that examines possible treatments for the deficits observed. Furthermore, no attention is given within the literature to those treatment protocols that are used with children who have autism which might already be tapping into EF deficits. For example, no research as yet has examined the extent to which the environmental changes used in the TEACCH approach (Schopler, 1997) help children who have autism to overcome EF deficits in planning, organisation and cognitive flexibility.

In conclusion, from the literature reviewed, it would seem that there is a need for greater specificity in EF measures that account for the deficits observed in autism, developmental issues and associated learning disabilities. Research using such measures might enable future studies of EF in autism to develop profiles of EF skills that would not only assist in critically evaluating the importance of EF in autism (e.g. Turner, 1997), but would also provide important tools for the assessment of EF in clinical practise (Klinger & Renner, 2000) leading to possible treatment protocols for EF deficits observed in autism. However, it is acknowledged that development of molar measures, allowing greater specificity in assessment, requires a development in EF theory accounting for specific sub-components.

Conclusions

Despite a need for greater specificity within the literature, EF is thought to be a useful concept (Pennington & Ozonoff, 1996) describing a number of interrelated sub-skills necessary for purposeful, goal-directed activity, including volition, planning, purposeful behaviour and effective performance (Lezak, 1995). Using a number of key measures such as the WCST, this concept has been examined within the neuropsychology literature with reference to neurological underpinnings and functional expression. These measures have been the focus of significant criticism within the literature and there is a need for more advanced measures (e.g. Ozonoff, 1996).

Within the developmental neuropsychology literature, it is generally agreed that behaviours associated with EF such as planning, flexibility and self monitoring are evident throughout the lifespan (Welsh & Pennington, 1988). However, as in adult research, the measures employed within child studies have been criticised, suggesting a need for contemporary developmental neuropsychological measures of EF (Anderson, 1998).

In investigating EF deficits in children who have autism, a number of independent spheres of research and clinical practice are brought together: autism, child development, learning disabilities and neuropsychology, making a complex field of research. Moreover, the theoretical complexity of EF makes integration of this field problematic. However, the importance of EF in developing an understanding of autism is apparent (Russell, 1997) and EF has been implicated as an underlying impairment in a number of the features associated with autism (e.g. Ozonoff et al. 1991; Rogers & Pennington, 1991; Turner, 1997).

Existing studies within the field have attempted to evaluate the extent to which EF deficits are observed in autism when compared with control participants (e.g.

Goldstein et al. 2001). Studies using a variety of measures such as the WCST and TOH/TOL have identified that individuals who have autism show greater deficits in EF than do matched controls (e.g. Ozonoff et al. 1991; Bennetto et al. 1996; Liss et al. 2001) with relatively few studies identifying negative results (e.g. Minshew et al. 1992). However, many of the studies have employed measures that tap multiple functions of EF, suggesting a need for greater specificity in measurement (Ozonoff & Pennington, 1996). Moreover, despite the empirical finding that approximately 75% of individuals who have autism have learning disabilities (e.g. Carr, 1999), only 3 of the 25 studies reviewed examined individuals who have autism and learning disabilities. A final criticism of existing studies is that little discussion is given to the issue of selecting and developing measures that are sensitive to the triad of impairments observed in autism and are not influenced by such deficits. Whilst the fact that most studies have identified significant EF deficits in individuals who have autism supports the hypothesis that EF is an underlying impairment in autism (Russell, 1997), the criticisms highlighted suggest a need for areas of improvement in empirical research within this field.

The literature review completed identifies a number of key recommendations for research. Specifically, it is suggested that there is a need for measures that tap explicit sub-components of EF, thus allowing profiles of EF to be explored (Pennington & Ozonoff, 1996). Within autism, current reviews examining profiles of EF deficits have suggested that cognitive flexibility is a key deficit in autism (Pennington & Ozonoff, 1996) and is therefore a key area for future research. However, such measures should be sensitive to development (Anderson, 1998), learning disabilities (Hughes et al. 1994) and the deficits observed in autism. Such measures would allow researchers to accurately evaluate the importance of EF as an underlying impairment in specific features of autism and would provide clinicians with tools for the assessment of EF in children who have autism.

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Table 1. Measures of executive function.

Test	Executive abilities measured	Reference
Wisconsin Card Sorting Test	Set shifting	Milner (1964)
Trailmaking Test, Part B	Set shifting	Reitan (1958)
Tower of London	Planning	Shallice (1982)
Tower of Hanoi	Planning	Welsh, Pennington, Ozonoff, Rouse and McCabe (1990)
Go-NoGo Task	Inhibition	Welsh, Pennington, Ozonoff, Rouse and McCabe (1990)
Stroop Test	Inhibition	Shue and Douglas (1992)
Thurstone Word Fluency Test	Fluency	Golden (1978)
Design Fluency	Fluency	Jones-Gottman and Milner (1977)

Table 2. Studies examining executive function in autism.

Reference	Participants and ages	Measures and Results	Advantages	Disadvantages
Rumsey (1985)	9 Autism (HFA) 10 Control Age: 18-39	WCST PsvR*	Matched for age, sex, education, VIQ, PIQ.	Not matched for VIQ, FSIQ, SES. Only one test used. Inappropriateness of WCST
Schneider & Asarnow (1987)	15 Autism (HFA) 11 Schizophrenic 28 Control Age: 7-14	HFA vs Control WCST PsvR (NS)	Matched for age, SES.	Not matched for sex or IQ. Only one test used. Inappropriateness of WCST.
Rumsey & Hamburger (1988)	10 Autism (HFA) 10 Control Age: 18-39	WCST Cat** Trails B**	Matched for age, sex, education, handedness.	Not matched for IQ. Inappropriateness of WCST.
Szatmari, Tuff, Finlayson & Bartolucci (1990)	17 Autism (HFA) 26 Asperger Syndrome 36 Outpatient control Age: 8-18	(HFA vs Control) WCST PsvR** WCST Cat** WCST errors**	Matched for age, sex.	Not matched for IQ. Inappropriateness of WCST. Mixed disorders in control group.
Rumsey & Hamburger (1990)	10 Autism (HFA) 15 Dyslexic 25 Control Age: 18-39	Word fluency* WCST Cat**	Matched for age, sex, education, handedness.	Not matched for IQ. Inappropriateness of WCST.
Prior & Hoffmann (1990)	12 Autism (HFA) 12 LD 12 Control Age: 10-17	Mazes (time)** WCST PsvE* WCST errors**	Matched for sex, age, IQ. Adapted WCST.	Non-validated version of WCST.
Eskes, Bryson & McCormick	11 Autism (HFA)	Stroop (NS)	Matched on speed of reading words	Not matched for IQ. Both HFA and

(1990)	11 Control Age: 7-19		in black print.	mild LD participants used in autism group. Only one test used.
Ozonoff, Pennington & Rogers (1991)	23 Autism (HFA) 20 LD control Age: 8-20	WCST PsvR** TOH**	Matched for age, VIQ, PIQ, sex, SES.	Different numbers in matched groups. Only two tests. Inappropriateness of WCST.
Minshew, Goldstein, Muenz & Payton (1992)	15 Autism (HFA) 15 Control Age: 15-40	WCST PsvE (NS) WCST errprs (NS) Trails A* TrailsB (NS) Rey-Osterith**	Matched for age, PIQ, sex, ethnicity.	Inappropriateness of WCST.
McEnvoy, Rogers & Pennington (1993)	17 Autism ('developmental delay') 13 LD 16 Control Age: 3-7	A-not-B task (NS) DR Task (NS) SR Task* Alternation (NS)	Matched for age, verbal & non-verbal MA, Sex, SES.	
Hughes & Russell (1993)	60 Autism (LD) 60 LD control Age: 6-18	Windows** Detour reach**	Matched for age, verbal and nonverbal mental ability, sex. Large experimental groups.	Tests examined mental disengagement.
Hughes, Russell & Robins (1994)	35 Autism (HFA and LD) 38 LD control 47 Control Age: 5-18	ID/ED Task** TOL**	Matched for age, verbal and nonverbal mental ability. Large experimental groups. Computerised tests.	Not matched for sex.
Ozonoff & McEnvoy (1994)	17 Autism (HFA) 17 Control Age: 11-23	WCST PsvR** TOH**	Matched for age, VIQ, PIQ, sex, SES.	Inappropriateness of WCST.
Ozonoff, Strayer, McMahon & Filloux (1994)	14 Autism (HFA) 14 Tourette Syndrome	Go-noGo*	Matched for age, VIQ, PIQ, sex.	Only one test used.

	14 Control Age: 8-16			
Ozonoff (1995)	A: 12 Autism (HFA) 12Cotrol B: 12 Autism (HFA) 12 Control Age: 8-17	A: WCST Cat* WCST PsvR* WCST errors** B: Computer administered WCST (NS)	Matched for age, VIQ, PIQ. Computerised test.	Only one test used. Inappropriateness of WCST.
Bennetto, Pennington & Rogers (1996)	19 Autism (HFA) 19 LD Age: 11-24	WCST PsvR** TOH** Working memory sentence span** Working memory counting span** Temporal Order (words)* Temporal Order (pictures)*	Matched for age, VIQ, PIQ, sex, SES.	Control group made up of non-autistic learning disorders (e.g. ADHD, dyslexia and borderline LD). Inappropriateness of WCST.
Ciesielski and Harris (1997)	19 Autism (HFA) 16 Control Age: 12-35	WCST* Halsted category test* Ambiguous figure test* Luria motor reversal test*	Matched for age and SES.	Not matched for sex, suitability of WCST, FSIQ. Study spanned child and adult populations. Inappropriateness of WCST.
Minshew, Goldstein & Siegel (1997)	33 Autism (HFA) 33 Control Age: 12-40	Trail Making B (NS) WCST PsvrE (NS) Rey-Osterrieth Copy (NS)	Matched for age, education (years), SES, VIQ, PIQ, FSIQ, sex.	Inappropriateness of WCST.
Griffith, Pennington, Wehner & Rogers (1999)	18 Autism (LD) 17 Control (various developmental delays) Age: 3-5	A not B (NS) Object retrieval (NS) A not B with invisible displacement (NS) 3-Boxes stationary and scrambled	Matched for age, verbal mental age and nonverbal mental age, and SES.	Control group included a number of co-morbid disorders such as Down syndrome and specific speech/language delays.

		(NS) 6-Boxes stationary and scrambled (NS) Spatial reversal (NS)		
Ozonoff & Jensen (1999)	55 Autism (HFA) 31 Tourette syndrome 31 ADHD 33 Control Age: 6-18	(HFA Vs Normal) WCST** TOH** Stroop (NS)	Matched for age. Large experimental groups.	Not matched for FSIQ, PIQ, VIQ. Inappropriateness of WCST.
Russell, Jarrold & Hood (1999)	21 Autism (LD) 19 Moderate Learning Disabilities 19 Control Age: 7-18	Modified Stroop (NS)	Verbal mental age.	Not matched for NVIQ and little information provided about participant characteristics.
Goldstein Johnson & Minshew (2001)	103 Autism (HFA) 103 Control Age: mean 18 years	Trail making A** Trail making B** Stroop* WCST PsvE*** WCST Cat** WCST errors (NS)	Matched for age, FSIQ, VIQ, PIQ, education level, sex. Large experimental groups.	Inappropriateness of WCST
Liss, Fein, Allen, Dunn, Feinstein, Morris, Waterhouse & Rapin (2001)	18 Autism (HFA) 34 Developmental language disorder Age: mean 9 years	WCST PsvE*** WISC-R Mazes (NS) Underlining test (NS) Rapid automized naming (NS)	Matched for age, SES, FSIQ, VIQ.	Not matched for VIQ or sex. Inappropriateness of WCST.
Shu, Lung, Tien & Chen (2001)	26 Autism (HFA) 52 Control Age: 6-12	WCST PsvE* WCST PsvrR* WCST Cat**	Matched for age. Computerised test.	Not matched for sex, SES, VIQ, PIQ, FSIQ (IQ measures not available for all subjects).

		WCST errors**		Inappropriateness of WCST.

* p<0.05, **p<.01, ***p<0.001, NS=non significant.

LD= Learning disability, HFA=High functioning autism, FSIQ= Full-scale IQ, PIQ= Performance IQ, VIQ= Verbal IQ, SES = socio-economic status, MA= Mental ability.

WCST= Wisconsin card sorting test, WCST Cat= WCST number of categories, WCST PsvE= WCST perseverative errors, WCST PsvR= perseverative responses, TOL= Tower of London, TOH= Tower of Hanoi.

Executive Function in Autism: A Comparative Study

Abstract

Existing empirical research using conventional measures of executive function (EF) has shown significant deficits in EF in individuals who have autism, particularly in the sub-component of cognitive flexibility. Indeed, EF has been implicated as an underlying cognitive impairment in autism. However, it has been suggested in the literature that there is a need for measures that are able to assess specific EF sub-components in isolation. The aim of the present study was to investigate EF in children with autism, using a battery of measures specifically designed to assess cognitive flexibility in children with autism and moderate learning disabilities. It was hypothesised that children with autism would show deficits in cognitive flexibility. Participants included an experimental group of children with a primary diagnosis of autism (n=12) and a control group of children with moderate learning disabilities (n=11) matched for age, verbal ability and non-verbal ability. Existing EF measures used included the NEPSY Design Fluency test, an Alternating Patterns test, and the Tinkertoy test. Adapted measures included a modified version of the adapted Weigl. Newly developed measures included the Box-Light test, and the Brick Design-Fluency test. Floor effects were identified for two of the measures (the NEPSY Design Fluency and the Adapted Modified Weigl) and ceiling affects were identified for two of the measures (the Alternating Patterns test and the Box-Light test). For those measures where no floor or ceiling effects were identified (the Brick Design Fluency test and the Tinkertoy test), no significant differences were identified between the experimental and matched control groups. This findings

does not support the majority of existing empirical evidence and does not support the notion of EF as an underlying impairment in autism. However, the methodological problems identified in the study make findings necessarily tentative in nature.

Key words: autism; executive function; cognitive flexibility.

Introduction

Autism

Current diagnostic criteria for autism is typically discussed with reference to two independent, though interlinked systems: DSM-IV (American Psychiatric Association, 1994) and ICD-10 (World Health Organisation, 1992) diagnostic criteria. Autism is a behavioural syndrome, defined by a cluster of behaviours (Romanczyk, Lockshin & Navalta, 1994) with both diagnostic systems using the three core-defining features of autism as the basis for diagnosis: impairments in socialisation, impairments in verbal and nonverbal communication and restricted and repetitive patterns of behaviours. However, it has been argued that in order to develop a comprehensive understanding of a developmental psychopathology, a shift is required from descriptive accounts to causal processes and underlying mechanisms (Rutter, 1988). Despite relatively accurate diagnostic descriptions of autism, psychological understanding of underlying impairments is less comprehensive (Ozonoff, 1995a). The theoretical basis of autism within psychology focuses on three distinct, though interconnected theories: Theory of Mind, Central Coherence and Executive Function (EF).

Theory of mind is a cognitive mechanism that should come on line in the second year of life (Leslie, 1987) and involves a person postulating the experience of mental states and then using these to explain and predict another person's behaviour (Baron-Cohen, 1989). Deficits in theory of mind have been shown to be apparent in autism (Baron-Cohen, Leslie & Frith, 1985, 1986) and have been implicated as an underlying cognitive impairment producing deficits in social ability (Frith, 1989), communication (Happe, 1993), imagination (Lillard, 1993) and repetitive and restricted behaviours (Baron-Cohen, 1989). An alternative psychological theory, though less researched, focussing on perception, is that an underlying problem in autism is a weak drive for central coherence (the ability to draw together diverse information to construct higher-level meaning in context) (Frith, 1989). Thus, rather than making sense of the global features of a situation, individuals who have autism perceive the world in a piecemeal way (Frith & Happe, 1994), perceiving the detail rather than the gestalt. Weak central coherence has been used to explain the deficits observed in autism in relation to the processing of part-whole relationships (Frith, 1989). In contrast to the narrow focus of theory of mind or central coherence, is the broader psychological theory (Bailey, Philips & Rutter, 1996) that individuals who have autism demonstrate deficits in executive function (e.g. Hughes, Russell & Robbins, 1994; McEnvoy, Rogers & Pennington, 1993). EF has been implicated as an underlying cognitive process in relation to theory of mind (Russell, 1997), central coherence (Pennington, Rogers, Bennetto, Griffith, Reed & Shyu, 1997) and repetitive behaviour (Turner, 1997).

Executive function

EF is described as an umbrella term, encompassing a number of interrelated sub-skills necessary for purposeful, goal-directed activity (Lezak, 1995; Stuss & Benson, 1986), sometimes described as maintaining an appropriate problem-solving framework (Bailey et al. 1996). A key linking feature of all EFs is that they are goal-directed and future-oriented (Welsh & Pennington, 1988; Welsh, 2002) and all involve the ability to disengage from the immediate environment and/or external context and guide behaviour instead by mental models or internal representations (Dennis, 1991). Lezak (1995) has proposed four key components of EF: volition, planning, purposeful behaviour and effective performance, each of which involves further sub-components. Pennington et al. (1997) concluded that the term 'executive function' is widely used to refer to the cognitive processes involved in the planning and execution of complex behaviour, without necessarily specifying what those processes are more precisely. This position lacks theoretical precision and makes comparison of studies examining EF problematic, suggesting a need for greater specificity within the literature.

Measures of EF typically used in research include: The Wisconsin Card Sorting Test (WCST: Milner, 1964), the Tower of London (TOL: Shallice, 1982) and the Tower of Hanoi (TOH: Welsh, Pennington, Ozonoff, Rouse & McCabe, 1990). Despite their wide use in studies as well as in clinical practice, a number of EF assessment measures suffer from four key problems identified by Pennington and Ozonoff (1996): 1) they are not well defined, 2) do not allow the identification of component processes, 3) are not always reliable and normally distributed, and 4) do not appear to be sensitive to the same underlying processes across a range of performance. Pennington and Ozonoff (1996) suggested that measures such as the Wisconsin Card Sorting Test (WCST) or the Tower of Hanoi, tap multiple EFs as well as other components (e.g. memory). This makes differentiation of EF components and comparison between clinical groups difficult, since two groups might obtain the same score on a test, but have deficits in different components of EF. They argued that such tests involve social processing, specific knowledge (e.g.

number and colour) and suffer from sensitivity and ceiling problems. Despite criticism of existing measures, such tests are still commonly used as indicators of EF deficits. Contemporary neuropsychology would argue that this approach is too simplistic and that it is critical to carefully evaluate assessment tools, considering the specific components of EF that they measure (Anderson, 1998).

Executive Function in Development

Developmental psychologists agree that behaviours associated with EF such as planning, flexibility and self monitoring are evident throughout the life span (Welsh & Pennington, 1988). Indeed, executive function has been successfully assessed in infants (Espy & Kaufmann, 2002) and in normally developing children (Kelly, 2000). It is thought that EFs develop in a stage-like manner, consistent with growth spurts observed in the central nervous system (Anderson, 1998). Evidence has suggested that key stages in EF development occur during middle childhood and later at adolescence (Anderson, Anderson & Lajoie, 1996; Becker, Isaac & Hynd, 1987; Passler, Isaac & Hynd, 1985; Kelly, 2000; Levin et al. 1991; Welsh, Pennington & Groisser, 1991). However, studies have not examined EF using consistent definition or measures and whilst it is thought that development occurs in parallel to development of the frontal lobes, development in other cerebral areas also needs to be considered to incorporate the emergence of memory, language and processing abilities (Anderson, 1998). Moreover, it has been argued that there is a need for deficits to be assessed in comparison to normative developmental ability, rather than adult ability (Welsh & Pennington, 1988).

In the application of existing EF measures to child populations, standardised administration procedures are available, for example, the Complex Figure of Rey, Tower of London/Hanoi, Controlled Oral Word Association, WCST, Trail Making Test, and Stroop Test (Anderson, 1998). However, these measures are typically derived from adult tests, sometimes with the use of child instructions (e.g. Golden, 1978) and may not be adequately validated or normed, making interpretation of existing studies problematic (Anderson, 1998). Indeed, it is not only the use of adult tasks with children that it problematic, as tasks developed for older children may not actually tap the same functions when used with younger children (Klinger & Renner, 2000).

Executive Function in Autism

Ozonoff (1995a) argued that a number of the key features of autism are reminiscent of the EF deficits that follow frontal lobe injury. For example, the behaviour of individuals who have autism is often rigid, inflexible, perseverative and impulsive, with individuals seemingly able to posses large stores of information but not able to use it correctly. The growing evidence for EF deficits in autism has led to the suggestion that deficits in EF may be of primary importance to the pattern of behaviours observed in autism (Turner, 1997). Indeed, EF has been highlighted as an underlying cognitive impairment in theory of mind (Russell, 1997), emotion perception (Ozonoff, Pennington & Rogers, 1991), imitation (Rogers & Pennignton, 1991), pretend play (Harris, 1993) and repetitive behaviour (Turner, 1997).

Preliminary studies of EF in adults who have autism, using single-case methodology, and existing neuropsychological measures such as the Wisconsin Card Sorting Test (WCST: Milner, 1964), identified perseverative responses and the use of rigid and inflexible problem-solving strategies (Steel, Gorman & Flexman, 1984). Early empirical studies using multiple participants and control groups (e.g. Rumsey, 1985; Rumsey & Hamburger, 1988; Szatmari, Tuff, Finlayson & Bartolucci, 1990; and Rumsey & Hamburger, 1990) corroborated these findings, suggesting that individuals with autism demonstrate impaired performance on the WCST when compared to matched controls, particularly in perseverative errors.

More recent studies, using the WCST, have supported these early findings in both adults and children with autism (Szatmari, 1990; Ozonoff, Pennington & Rogers, 1991; Ozonoff, Rogers, Farnham & Pennington, 1993; Ozonoff & McEnvoy, 1994; Ozonoff, 1995b; Bennetto, Pennington & Rogers, 1996; Ozonoff & Jensen, 1999; Goldstein, Johnson & Minshew, 2001; Liss et al. 2001; Shu, Lung, Tien & Chen, 2001) particularly with reference to perseverative errors. However, differences are not isolated to the WCST alone. Adults with autism have also been found to show impaired EF abilities when tested using the Word Fluency test (Rumsey & Hamburger, 1990), the TOH/TOL (Ozonoff and McEnvoy, 1994), Trails A (Minshew, Goldstein, Muenz & Payton, 1992; Goldstein et al. 2001), Trails B (Rumsey & Hamburger, 1988, Goldstein et al. 2001) and the Rey-Osterreith (Minshew et al. 1992). Children have also been found to show impaired EF abilities when tested using the TOL/TOH (Ozonoff et al. 1991; Hughes et al. 1994; Ozonoff and McEnvoy, 1994; Bennetto et al. 1996; Ozonoff & Jensen, 1999), Trails A

(Minshew et al. 1992; Goldstein et al. 2001), Trails B (Rumsey & Hamburger, 1988, Goldstein et al. 2001), Mazes (time) (Prior & Hoffmann, 1990) Rey-Osterreith (Minshew et al. 1992), Windows, Detour Reach (Hughes & Russell, 1993), ID/ED Task (Hughes, Russell & Robins, 1994), Go-no-Go (Ozonoff, Strayer, McMahon & Filoux, 1994), Temporal Order (words and pictures) (Bennetto et al. 1996), and the Stroop test (Goldstein et al. 2001). Thus, there exists a relatively large body of evidence that supports the supposition that EF deficits are apparent in autism.

In contrast to the research presented above, a number of studies using the WCST have not identified deficits in children who have autism when compared to controls (e.g. Schnieder & Asarnow, 1987; Minshew et al. 1992). Moreover, some studies have not identified EF deficits in children who have autism using: the Stroop (Eskes, Bryson & McCormick, 1990, Ozonoff & Jensen, 1999), Modified Stroop (Russell, Jarrold & Hood, 1999), Trails B (Minshew et al. 1992), A not B task (McEnvoy et al. 1993; Griffith et al. 1999) Alternation task (McEnvoy et al. 1993), TOH (Ozonoff, 1995b), Rey-Osterreith Complex Figure (Minshew et al. 1997), working memory sentence span, working memory counting span (Bennetto et al. 1996), object retrieval, A not B with invisible displacement, 3-boxes, 6 boxes, spatial reversal (Griffith, Pennington, Wehmer & Rogers, 1999) underlining test, and rapid automatized naming (Shu et al. 2001). Such findings strongly refute the EF theory of autism, since for EF to be seen as an underlying cognitive deficit, it should be expected that EF deficits are universal to all individuals who have autism (Turner, 1997).

Methodological Problems in Existing Research

Despite criticism within the literature of the WCST as a valid measure of EF, the vast majority of existing studies have used the WCST as a primary measure of EF. When one considers Pennington and Ozonoff's (1996) suggestion that measures such as the WCST and the TOH tap multiple EFs as well as other cognitive components, it would seem that few of the studies show any specificity of measures. Moreover, despite the critical importance of taking developmental issues into consideration when considering EF (Welsh & Pennington, 1988), the relative dependency of child studies on traditional EF measures such as the WCST (8 of the 13 child studies used this measure) is problematic since these measures do not account for developmental level (Anderson, 1998).

Whilst at least 25 studies exist within the literature that have used control groups to examine EF in autism, the methodology employed in matching and selection of participants in these studies is inconsistent. Three areas of poor matching can be identified. Of primary consideration, is the need for ability-matched groups, since it has been argued that there is a correlation between measures such as the WCST and verbal intelligence (Reader, Harris, Schuerholz & Denckla, 1994). The finding that individuals who have autism typically have poorer verbal intelligence than non-verbal intelligence (Lincoln, Allen & Kilman, 1995) suggests the need for measures that tap both domains. Of studies identified using matched control groups, only approximately half were matched for VIQ and PIQ. Secondly, despite autism being more common in males, in a ratio of about 4:1 (Gillberg & Coleman, 1992), only half of the identified studies specify gender matching. A final matching criticism of existing literature is the use of other clinical groups such as ADHD, dyslexia and borderline LD in control groups (e.g. Bennetto et al. 1996). Given the finding that individuals who have other developmental disorders (e.g. ADHD) may demonstrate deficits in EF (Pennington & Ozonoff, 1996) using such individuals in control groups may affect results.

Contrary to existing findings, Ozonoff (1995b) identified that whilst children who have autism perform worse than controls using a traditional version of the WCST, using a computerised version, group differences are non-significant. It has been suggested that the reduction of unintentional task demands (e.g. social and verbal demands) in the computerised version may in part, be responsible for this finding (Ozonoff, 1995b). This not only suggests that the traditionally administered WCST may be an inappropriate measure for children who have autism, but also highlights the need for newly designed measures within this field that reduce extraneous task demands and isolate specific EFs (Ozonoff, 1995b). Although it is difficult to assess to what extent EF studies account for the deficits observed in autism, there is some evidence that characteristic features of autism may affect investigations of EF. For example, it has been shown that children who have autism are known to perform better than control participants matched for mental age on the Block Design subtest of the Wechsler Intelligence Scales (Wechsler, 1981) than would normally be predicted by developmental level, which has been explained in terms of central coherence (Shah & Frith, 1993). It is possible that existing EF measures also tap into skills and deficits associated with autism in this way and so affect findings. However, little discussion is given to this issue within the literature with the exception of computerised measures and the reduction of unintentional task demands on children who have autism (Ozonoff, 1995b; Hughes et al. 1994).

A final criticism of existing research is that despite a recent population study (Baird, 2000) cited in the Medical Research Council's (2001) review of autism research, which suggests that approximately 25 per cent of individuals who have autism have IQs below 70, the vast majority of studies examining EF in autism examine high functioning individuals. Moreover, of those studies examining individuals who have learning disabilities, many have used the same tests that are used within normally developing populations (e.g. Russell et al. 1999).

Future Research

To properly identify possible EF deficits in children who have autism, and to subsequently assess the nature of EF as an underlying cognitive impairment in autism, future research must carefully consider a number of critical issues. Primarily, a dependence in the literature on the use of global measures of EF such as the WCST and the TOH that may tap multiple EFs, suggests a need for discrete EF measures, tapping sub-components of EF is required in order to more accurately identify the exact nature of EF deficits in autism (Pennington & Ozonoff, 1996), breaking down components into sub-components of EF and examining the nature of such sub-components, thus accessing only one specific skill (Griffith et al. 1999). The development of molar EF measures that are able to accurately assess sub-components of EF would thus allow clinicians and researchers to measure profiles of EF in individuals (Pennington & Ozonoff, 1996). Such measures could be used in diagnosis and assessment of autism (Klinger & Renner, 2000) and would allow for a more accurate empirical validation of the importance of EF as an underlying impairment in autism (Turner, 1997) since these measures would allow the nature, specificity and variability of EF in autism to be more closely assessed.

Secondly, as has been highlighted, most available EF measures have been developed for use with adults and their inclusion in assessment is based on the assumption that they will detect similar dysfunction in children (e.g. Anderson, 1998; Pennington & Ozonoff, 1996; Welsh et al. 1991). Thus, there is a clear need for further measures that are sensitive to developmental level and that also engage children using fun, motivating tasks. Stemming from this problem, is the need for measures that are sensitive to issues of cognitive ability since many of the existing studies examining individuals who have learning disabilities use the same tests that are used within normally developing populations (e.g. Russell et al. 1999). Thirdly, in studies examining the prevalence of EF deficits in autism, there is a need for measures that assess EF in isolation to the behavioural impairments observed in autism. For example, Ozonoff (1995b) and Hughes et al (1994) both discussed the relevance of using computerised measures with children who have autism, since such children are anecdotally reported to interact well with computers (which may be due to the removal of a social interaction with another person). Thus, further EF measures should be developed that account for the triad of impairments observed in autism as well as deficits in theory of mind, central coherence and sensory difficulties. A further area that merits development in future research is the need for well-matched studies using appropriately selected participants (Pennington & Ozonoff, 1996).

This study

This study examines EF in children who have autism and moderate learning disabilities. Existing research has suggested that cognitive flexibility is a key area of EF deficit in autism (Pennington & Ozonoff, 1996). However, this is not explored within the literature and is generally only discussed with reference to the perseverative responses observed in the WCST (e.g. Ozonoff & McEnvoy, 1994), a measure that gives an indication of cognitive flexibility but is very broad. In line with the need for studies that examine specific EF deficits observed in autism (Pennington & Ozonoff, 1996) this study focuses on cognitive flexibility.

The sub-components illustrated in the following model have been taken from descriptions of cognitive flexibility and are one way of examining this field. They are not supported by factor analysis and are not meant to provide an overall model of cognitive flexibility. Instead, they have been incorporated to assist the reader in developing a conceptual understanding of the different sub-components described in the literature and the different measures incorporated within this study.

The language used to describe each of the sub-components of cognitive flexibility differs between researchers. For example, Spreen and Straus (1991) described the generation of alternatives (as assessed by design fluency measures) as 'spontaneous flexibility', whereas Turner (1997) described this same concept as 'generativity'. However, despite using different language, the domains described and the measures reported in the literature are consistent. Since researchers have used different terms to describe the same concepts, some way of summarising this terminology is required. As such, this study uses the following terms to describe the sub-components identified in the literature: creativity, perseveration and set-shifting. In examining EF in autism, Turner (1997) has made the distinction between creativity (called 'generativity'), perseveration (called 'recurrent perseveration') and set-shifting (called 'stuck in set perseveration'). Morover, Spreen & Straus (1991) have made a conceptual distinction between creativity, perseveration and set-shifting and Ozonoff & Strayer (1997) have made a distinction between creativity and perseveration, although terminology of these same sub-components differs. Other researchers have highlighted creativity (Jarrold, Boucher & Smith, 1993), perseveration (Lezak, 1995) and set-shifting (Bailey, Philips & Rutter, 1996) as independent sub-components, again using differing terminology. As such, each of the three sub-components used in this study has been extracted from the literature.

1. Creativity involves those skills that enable the participant to create a series of different designs (thus, shifting from one created design to an alternative created design). Creative imagination is a required skill in completing these activities (Lezak, 1995).

2. Perseveration involves those skills that enable the participant to copy a changing design, incorporating all elements of the design, rather than becoming 'stuck' on specific parts of it. This skill is described as one of the hallmarks of the capacity to shift responses (Lezak, 1995).

3. Set shifting involves those skills that enable an individual to form a concept and then shift cognitive set from one concept to another (Lezak, 1995).

In this way, cognitive flexibility can be examined in its constituent parts (as defined by this model), each conceptually distinct from the others. This is in line with the need for discrete EF measures, tapping sub-components of EF (Pennington & Ozonoff, 1996) accessing very specific skills (Griffith et al. 1999).

A battery of measures was developed to examine each of these sub-components of cognitive flexibility in children who have autism and moderate learning disabilities. Measures were identified from the literature where possible although it was necessary to design and build further measures where existing tests were felt not to be appropriate. Measures were selected and/or created that were judged to be developmentally appropriate to the participant group identified and would be of interest to and fun for children in the age range specified. Moreover, the measures were judged to be sensitive to issues associated with the impairments observed in autism. For example, requiring minimal social interaction and verbal communication and judged not to be affected by central coherence (as is observed in the block-design subtest). Moreover, measures were selected that were judged to have little memory load, in that participants had physical and verbal prompts throughout, thus isolating specific EF skills from memory.

Measures selected to assess creativity were: the NEPSY design fluency test (Korkman, Kirk & Kemp, 1998), the Tinkertoy test (Lezak, 1995; Malcom, 1993) and a brick design fluency test. The NEPSY design fluency subtest has modest reliability (r=.59) based on test-retest correlation and acceptable interrater reliability (Korkman et al, 1998). Although the Tinkertoy test has been shown to correlate significantly (P<0.005) with other EF measures such as the WCST (Mahurin, Flanagan & Royal, 1993) no normative data is available. The brick design fluency test was developed for this study and involves constructing rather than drawing designs (to avoid the need for fine motor skills as is found in standard measures of design fluency) and as such no data concerning the reliability or validity of this measure is available.

Measures selected to assess perseveration were: the alternating patterns test (Lezak, 1995) and a box-light test that was developed for this study. Although the alternating patterns test is an accepted clinical measure (Lezak, 1995), no data is available concerning the reliability or validity of this measure. The box-light test was developed for this study and involves the participant copying a pattern without the need for drawing skills (as is required in the alternating patterns test). As such no data concerning the reliability or validity of this measure is available.

The measure selected to assess set-shifting was an adapted version of the Modified Weigl (the Modified Weigl was developed by DeRenzi, Faglioni, Savoiardo & Vognolo, 1966). Given that this is an adapted measure, no data concerning reliability or validity is available.

Based on existing research examining EF in autism, showing deficits in cognitive flexibility, it was hypothesised that children with autism and moderate learning disabilities would perform less well on these measures of cognitive flexibility than would a matched control group of children with moderate learning disabilities and no other psychiatric diagnosis.

Method

Design

A between groups experimental design was employed. Two groups were used: 1) an experimental group consisting of children with autism and moderate learning disabilities, and 2) a control group of children with moderate learning disabilities. The independent variables were the group that the children were assigned to (autism or control) and the two ability measures used for matching. The dependent variables were the six EF measures employed.

Participants

23 children between the ages of 6-12 years were recruited from MLD schools. Given that autism is more common in males, in a ratio of approximately four to one (Gillberg & Coleman, 1992) only males were used within the study.

Inclusion criteria specified that all participants within the study should be: between six and twelve years of age (thus limiting developmental differences between participants), male (due to the gender differences observed in autism), and have either formal diagnoses of autism and learning disabilities using ICD-10 diagnostic criteria (WHO, 1992) or a diagnosis of learning disabilities using ICD-10 criteria

(WHO, 1992). Exclusion criteria specified that all participants within the study should not have known neurological difficulties, non-corrected visual impairments, motor deficits, epilepsy or co-morbid disorders such as ADHD.

An experimental group of boys (n=12, mean age=9.51 years) with a diagnosis of autism and moderate learning disabilities was compared with a control group of boys (n=11, mean age=8.93) with a diagnosis of moderate learning disabilities.

The two cohorts were assessed for verbal ability using the British Picture Vocabulary Scale (BPVS: Dunn, Dunn, Wheeton & Pintilie, 1982) and non-verbal ability using the Raven's Coloured Progressive Matrices (RCPM: Raven, 1965; Raven, Raven & Court, 1998). The BPVS is a measure of receptive vocabulary (verbal ability) and has been used widely as a matching procedure for studies of autism (e.g. Happe, 1996). It has been shown to have satisfactory reliability (0.75-0.86). The RCPM is a non-verbal measure of perceptual reasoning (non-verbal ability) and, like the BPVS, has been used as a matching procedure for studies of autism (e.g. Shah & Frith, 1983). It shows good test-retest reliability (0.86-0.92) (Raven et al. 1998). Instructions for the BPVS and RCPM were adapted, with complex language reduced (see Appendix 1 for full test battery and instructions).

Table 1 illustrates participant characteristics. In order to compare the groups for chronological age, verbal ability and non-verbal ability, 3 Mann Whitney U tests were conducted. The two groups did not differ significantly in chronological age ($U(12,11)=49$ $p>0.05$), verbal ability ($U(12,11)=63$ $p>0.05$) or non-verbal ability

(U(12,11)=40.5 p>0.05). As such, it is concluded that the two groups were adequately matched for chronological age, verbal ability and non-verbal ability.

Insert Table 1 about here

Experimental Measures & Scoring

A battery of six measures of cognitive flexibility was developed and administered to each of the participants. Three of the measures had been previously developed (the Alternating Patterns Test, the NEPSY Design Fluency Random Array and the Tinkertoy Test), one was an adapted measure (the adapted version of the Modified Weigl) whilst two were designed and constructed specifically for this study (the Box-Light Test and the Brick Design Fluency Test). Tests were administered in a pre-specified order using standardised instructions (see Appendix 1 for full test battery and instructions). The order of tests was standardised to aid motivation in that, several relatively easy measures were presented before a harder measure. This order is based on the principle of behavioural momentum, which suggests that positive and successful behaviour increases the likelihood of subsequent positive and successful behaviour (Ylvisaker & Fleeney, 1998). Ylvisaker & Fleeney (1998) argue that as such, problematic tasks (i.e. tasks likely to induce negative behaviour) should be introduced in the context of successful and non-problematic tasks. This principle has been validated in several studies using individuals who have developmental disabilities (e.g. Sanchez-Fort, Brady & Davis, 1995; Zarcone, Iwata, Mazaleski & Smith, 1994). However, such a presentation does not account for order effects. Fatigue may be a problem in fixed order presentations (Robson, 1993) in that poor performance on later measures is due to tiredness. Randomisation of the measures (Robson, 1993) might help to overcome this problem although would not allow the measures to be presented in order to aid motivation, a primary consideration of this study.

Creativity

NEPSY: Design Fluency (random presentation): The NESPY design fluency random array (Korkman, Kirk & Kemp, 1998) is a subtest designed to assess the ability to generate as many unique designs as possible by connecting up to five dots presented in a random array during a 60 second time period. Children are first shown how to connect the dots using a practise array, before starting the timed test. The design fluency subtest has modest reliability (r=.59) based on test-retest correlation and acceptable interrater reliability (Korkman et al. 1998). The participant was presented with the practise array and was told *"Here are some boxes with dots. I want you to connect two or more using straight lines, to make a design in each box. Make sure that each design is different from the others. Let's practice."* A line was drawn by the experimenter connecting two dots within the first box. The participant was then told, *"Now you do these, making sure every design is different."* The participant produced different designs in the remaining three practice boxes. Errors were explained until the child had correctly completed the teaching example. The random array was then presented and the participant was told, *"In every box, connect two or more dots with straight lines. Work as quickly* *as you can, and make every design different. Start here. Ready? Begin."* Responses were recorded on the scoring sheet. The total number of unique, correct designs was scored and recorded.

Brick Design Fluency Test Part A: In order to ascertain each child's understanding of the concept of 'same' and 'different', children are shown 2 different pictures (one illustrating a dog and one a hot air balloon: see Appendix 2 for picture) and were asked, *"Are these the same or different?"* The response provided by the child (e.g. *"they are the same*") was recorded and the child was then asked *"How are they the same/different?"* to ensure that the child's concept was correct or incorrect and not a guess. Children were then shown 2 identical pictures (both pictures illustrating hot air balloons: see Appendix 2 for picture) and the process was repeated. Responses were recorded on the scoring sheet.

Brick Design Fluency Test Part B: The Brick Design Fluency Test (see Appendix 3 for picture) was developed to measure the ability to create multiple constructions and to conceptually shift to each new, different construction. This measure is being piloted in this study and as such no data are available concerning reliability or validity. The participant was presented with a set of 12 coloured bricks and was asked, *"Can you make me something with these bricks?"* No time limits were set. When the construction was completed it was moved to the back of the desk and the child was asked, *"What is it?"* The name given to the construction by the child was recorded on the scoring sheet. A new, identical set of bricks was then presented and the child was told, *"That's really good. Now, can you make me something different?"* This process was repeated until the child had built four constructions in total. The names given to the constructions by the participant were recorded on the scoring sheet. A photograph was taken of the constructions at the end of the assessment for later analysis. The scoring system (see Appendix 1) firstly examines each construction compared to the previous construction (i.e. 1 compared to 2, 2 compared to 3 and 3 compared to 4) examining physical changes (height, width, depth, persisting features) and name change. The total number of similarities is then noted in a second score which examines the same criteria of physical and name changes. A second experimenter was employed to score the photographs of the constructions to examine inter-rater reliability. The second rater was a Trainee Clinical Psychologist with experience in scoring psychometric measures and in the assessment of children with autism and moderate learning disabilities.

Tinkertoy Test (TTT): The TTT (Lezak, 1995, pp. 659) is a constructional test of executive ability. The participant is given 50 standardised pieces of a Tinkertoy set (an American construction toy) and is asked to make a construction. Although the TTT has been shown to correlate significantly ($P<0.005$) with other EF measures such as the WCST (Mahurin, Flanagan & Royal, 1993) no normative data are available. Importantly, an additional sub-score of *creativity* can be included in the scoring (Malcom, 1993). The fifty pieces of Tinkertoy were presented to the participant who was told, *"Make whatever you want with these. You will have at least five minutes and as much more time as you wish to make something."* If the participant did not start spontaneously, he was prompted by the experimenter taking one piece and connecting it with another. *"You see. The pieces fit together. Now you try. Make whatever you want."* When the participant had finished (allow at least 5 minutes of time) they were asked for the name of their object. The TTT complexity score (*comp*: Lezak, 1995) is obtained by indicating whether any combination of pieces was used (1 point), the number of pieces used (n<20=1, <30=2, <40=3, <or=50=4), whether the name was appropriate=3, vague/inappropriate=2, post hoc =1 or none=0, whether there was mobility=1 or moving parts=1, whether it was 3-dimensional (1 point) or free-standing (1 point). 1 point is taken for each mistake made (e.g. error misfit, incomplete fit). Thus, a maximum score of 12 is possible. TTT creativity score (*create*: Malcom, 1993) is obtained in the following system: no name or inappropriate name= 0 point, real object with pieces of 30 or less= 1 point, real object with pieces of more than 30= 2 points, imaginary object with pieces of 30 or less= 2 points, and imaginary object with pieces of more than 30=3 points). Thus, a score of 0-3 is possible. A photograph was taken of the objects constructed in the brick design fluency test and the TTT for later analysis. If it was a desired activity, children assisted in taking the photograph of their work. It is acknowledged that the TTT has little data concerning validity or reliability.

Perseveration

Alternating Patterns Test: The alternating patterns test is a simple test of perseveration illustrated by Lezak (1995, pp. 671) which is based on tests of perseveration that require the participant to copy and maintain alternating patterns or letters (see also Christiansen, 1979; Luria, 1966 for further examples). The participant was presented with a white A4 sheet of paper on which was printed a pattern of squares and triangles along a single line (Appendix 4). The experimenter explained, *"Do you see this line? It has a pattern to it. I would like you to continue* *the pattern, like this"* and demonstrated to the participant the continuation of the pattern using a pencil for approximately ten seconds. A new, identical sheet was then presented to the participant who was told, *"Draw the line and keep going until I tell you to stop."* The child was then timed for one minute before being told to *"Stop"*. The responses were operationally defined: *correct* (the line was continued as demonstrated in the example), *incorrect* (the line was a random pattern) or *perseverative* (the child was stuck on a repetitive incorrect pattern for more than three objects, i.e. three squares in a row). Responses were recorded on the scoring sheet. No data are available concerning the reliability or validity of this measure. However, the alternating patterns test is a recognised clinical tool that is reported in the literature to measure perseveration in clinical populations (e.g. Lezak, 1995, Luria, 1966). Whilst it is acknowledged that this is a non-validated measure, no alternative, well-validated measure of perseveration was available that fulfilled the test selection criteria specified in this paper (page 16).

Box-light Test: The Box-light Test (see Appendix 5 for picture) was developed for this study to measure perseveration in a format that uses limited verbal instructions and writing skills. The child is presented with a black box (length=37cm x width=24cm x depth=7.5 cm) with two green buttons (left and right) and two lights (left=white, right=orange). Each button lights the corresponding light. The child is asked to copy a pattern that the experimenter demonstrates (e.g. left, right, left, right etc.). The child is then asked to copy two different patterns. The child is observed to see if he is able to shift to each new pattern or becomes 'stuck' on an old pattern or a repetitive response (e.g. left, left, left, left). This measure is being piloted in this study and as such no data are available concerning reliability or validity. The responses were operationally defined: *correct* (the pattern was continued as demonstrated), *incorrect* (the pattern was random) or *perseverative* (the child was stuck on a repetitive incorrect pattern or a previous pattern for more than six pushes of the buttons). Responses were recorded on the scoring sheet.

Set-Shifting

Adapted Version of the Modified Weigl: The Weigl Test, modified version (De Renzi et al. 1966) assesses the ability to sort a series of objects and then conceptually shift to a different sort. Blocks of four colours, 3 shapes, 2 thicknesses, 4 patterns and a spontaneous sort allow 5 different sorting principles. The test used in this study is an adapted form of the De Renzi et al (1996) modified version in that pictures of bees, trumpets and dogs are placed on the pieces, rather than card suits (club, heart, diamond), allowing further sorts (see Appendix 6 for picture). Twelve wooden pieces (4 circles, 4 squares, 4 triangles) of different colour (3 red, 3 green, 3 blue, 3 yellow) size (6 small, 6 large) thickness (6 thin, 6 thick) and with different pictures presented on top (3 bees, 3 clocks, 3 dogs, 3 trumpets) are used. Possible sorts include: colour, shape, thickness, size and picture (instruments and animals or clocks, dogs, bees, trumpets). Although no normative, reliability or validity data are available for this test, it has been piloted successfully at the University of Southampton using normally developing children. The twelve pieces were presented to the child who was told, *"This is a sorting game. Can you sort these out? Which ones go together?"* If the participant could not understand the instructions, a first sort was shown by the experimenter (dogs, bees, clocks and trumpets) and the child was told, *"Can you sort them a different way?"*. If the participant could not understand the instructions, a second sort was shown by the experimenter (triangles, circles and squares). The child scored 2 points for each correct sort. Responses were recorded on the scoring sheet.

Procedure

The study received ethical approval from the University of Southampton (Appendix 7). Three of the MLD schools approached within the local education authority were able to provide participants for the study. An information sheet and consent form (Appendix 8) was sent to parents of those children identified as matching inclusion criteria for the study. This information was judged to be appropriate for parents by the Head-teacher and teaching staff at each of the schools. Once informed consent had been obtained from parents, each child was asked if they would like to take part in the study.

Given the need of some children who have autism and/or learning disabilities for routine and predictability, children were reminded several times before testing that they would be leaving the classroom. Moreover, the experimenter engaged with the child in a classroom activity prior to testing in order for the child to become familiar with the experimenter. It was then explained to children, *"We are going to do some puzzles in 'X' room now and when are finished we will come back to the classroom."* Children at each of the three schools used in the study were tested in a familiar room, free from distractions using a low classroom table with two classroom chairs. The measures were presented in eight identical plastic trays on the desk in the room, children were encouraged to look at all of them and were told, *"We are going to do 1,2,3,4,5,6,7,8* (each of the tests were pointed at to provide a visual cue rather than an abstract number) *puzzles and then we will finish and we will go back to the classroom. If you want to stop then tell me so."* Only when the child was happy to continue was testing commenced. Measures were administered in the following order: BPVS, RCPM, Box-light test, Adapted version of the Modified Weigl, Alternating Patterns test, brick-design fluency test, NEPSY design fluency test, and the Tinkertoy test. This order was chosen to ensure that several easy measures were preceded by a more difficult measure, thus building a child's confidence in easy tasks before a more difficult task is presented. It is based on the principle of behavioural momentum, which suggests that positive and successful behaviour increases the likelihood of subsequent positive and successful behaviour (Ylvisaker & Fleeney, 1998). Children were monitored closely for any possible signs of distress during testing. Although none of the children showed any signs of distress it had been agreed that should they do so, testing would be discontinued immediately. When testing was completed the child was congratulated for doing well and told that it was now time to return to the classroom. The class teacher would meet the child at the entrance and welcome them back to the classroom to provide a clear visual and verbal cue for transitioning back to the classroom.

Only one experimenter was used in the study, a final year Trainee Clinical Psychologist with experience in administering psychometric tests to children with autism and moderate learning disabilities.

Results

Analyses of Individual Measures

Table 2 illustrates mean scores for the EF measures employed. Mode scores are presented for the box-light and alternating patterns tests as these use nominal data and as such, mean scores would not be appropriate. Inspection of histogram plots (Appendix 9) suggested that data were not normally distributed and showed some bimodal distribution. In addition, Skewness statistics were calculated for each measure (Appendix 10) suggesting the presence of skewed data. As such, non-parametric statistics were employed.

Insert Table 2 about here

Creativity

NEPSY Design Fluency (random presentation): In order to examine for possible statistical differences between scores obtained by experimental and control groups on the NEPSY design fluency (random presentation), a Mann-Whitney U test was employed. No significant differences were identified between the experimental and control groups ($U_{(9,11)}=49.5$ $p>0.05$). For both groups, the mean score obtained was at the 4th percentile, suggesting that floor effects were present on this measure.

In addition, inspection of graph 9 (Appendix 9) indicates that data are positively skewed, indicating floor effects.

Brick Design Fluency: Firstly, to examine statistical differences between the experimental and control groups on sequential changes in the designs constructed by participants, a Mann-Whitney U test was employed. This illustrated no significant differences between the two groups on this variable ($U_{(11,11)}=58.5$ $p>0.05$). Secondly, to examine whether statistical differences exist between the experimental and control groups on total similarities identified in the designs constructed by participants, a Mann-Whitney U test was employed. This illustrated no significant differences between the two groups on this variable ($U_{(11,11)}=58.0$ $p>0.05$).

Tinkertoy Test: Firstly, to examine for statistical differences between the experimental and control groups on *complexity* scores obtained in the Tinkertoy test, a Mann-Whitney U test was used. No significant differences between the groups were identified ($U_{(11,11)}=46.5$ $p>0.05$). Secondly, to examine for statistical differences between the experimental and control groups on *creativity* scores obtained in the Tinkertoy test, a Mann-Whitney U test was used. No significant differences between the groups were identified ($U_{(11,11)}=56$ $p>0.05$).

Perseveration

Alternating Pattern Test: In order to examine whether there was a statistical difference between the number of correct, incorrect or perseverative responses given by participants in the autism and control groups on the alternating patterns test, a Chi-Square test was conducted on the data. No significant differences were identified between the experimental and control groups ($\chi^2(9,10)=1.351$, $p>0.05$). Inspection of Table 2 illustrates that the mode score obtained for both groups was 1 (i.e. 'correct') indicating that ceiling effects were present on this measure. Inspection of data in graph 8 (Appendix 9) indicates that data is positively skewed, also suggesting that ceiling effects were present.

Box-Light Test: In order to examine whether there was a statistical difference between the number of correct, incorrect or perseverative responses given by participants in the autism and control groups on each of the three patterns in the box-light test, three Man-Whitney U tests were conducted on the data. No significant differences were identified between the experimental and control groups in terms of the number of correct, incorrect or perseverative responses for pattern 1 ($U(12,11)=60.5$ $p>0.05$), pattern 2 ($U(12,11)=62$ $p>0.05$) and pattern 3 ($U(11,12)=57$ $p>0.05$). Inspection of Table 2 illustrates that the mode score obtained for both groups was 1 (i.e. 'correct') indicating ceiling effects on this measure. In addition, inspection of data in graphs 4,5 and 6 (Appendix 9) suggests that ceiling effects were present, in that data are positively skewed.

Set-Shifting

Adapted Version of the Modified Weigl: To examine whether there was a statistical difference between the experimental and control groups on performance of the modified Weigl test, a Mann-Whitney U test was conducted on the total scores. No significant differences were identified between the experimental and control groups ($U_{(12,11)}=48$ $p>0.05$). Inspection of Table 2 indicates that floor effects may be present for this measure (2.17 and 2.91 out of a possible total score of 12) indicating floor effects. In addition, inspection of graph 7 (Appendix 9) which indicates that data are positively skewed, suggests that floor effects are present.

Inter-rater Reliability

In order to examine the inter-rater reliability of the brick design fluency, a second rater examined photographs of the designs constructed, using the scoring system designed for this test. Cohen's Kappa statistics were calculated for the sequential changes and total similarities scores of this measure. For sequential changes, a kappa of 0.52 was calculated. Robson (1993) cites the 'rules of thumb' proposed by Fliess (1981) which indicate that 0.52 suggests 'fair inter-rater agreement'. For total similarities a kappa of 0.92 was calculated. This indicates 'excellent inter-rater agreement'. These data suggest that inter-rater reliability was acceptable for the scoring system used in the brick design fluency test.

Correlations

To examine the relationship between the measures Spearman correlations were conducted on the data (Appendix 12). Results illustrate significant positive correlations between the BPVS and the RCPM ($r(23)=0.542$, $p<0.01$), the BPVS and the Adapted Modified Weigl ($r(23)=0.538$, $p<0.01$), the BPVS and the NEPSY design fluency ($r(20)=0.528$, $p<0.05$), the Box-Light Pattern 2 and the Box-Light

Pattern 3 ($r(23)=0.768$, $p<0.01$), the Adapted Modified Weigl and the TinkerToy Test Complexity score ($r(22)=0.466$, $p<0.05$), and the Tinkertoy Test Complexity score and the TinkerToy Test Creativity score ($r(22)=0.634$, $p<0.01$). Significant negative correlations were identified between the RCPM and the Box-Light Pattern 3 ($r(23)=-0.435$, $p<0.05$), the RCPM and the Alternating Patterns Test ($r(19)=-0.475$, $p<0.05$), and the Brick Design Fluency Sequential Changes and the Brick Design Fluency Total Similarities ($r(22)=-0.959$, $p<0.01$).

Discussion

Summary of Primary Findings

Based on existing literature that has identified EF deficits in children who have autism, particularly in cognitive flexibility (Penningon & Ozonoff, 1996), it was hypothesised that children with autism and moderate learning disabilities would perform less well on measures of cognitive flexibility than would a matched control group of children with moderate learning disabilities. A battery was specifically designed to measure EF in children who have autism and learning disabilities, focussing on cognitive flexibility. Despite measures being selected for this ability group, floor effects were identified for the NEPSY Design Fluency and Adapted Modified Weigl tests and ceiling effects were identified for the Alternating Patterns Test and the Box-Light Test. As such, conclusions must necessarily be drawn from data taken from the Brick Design Fluency Test and the Tinkertoy Test. Results indicate that performance on these two measures did not significantly differ between the experimental and matched control groups, thus refuting the experimental hypothesis. Because normative data is not available for many of the measures, within-groups analysis is problematic and it is not possible to asses how children in the two groups performed compared to typically developing children. However, findings reported for the NEPSY design fluency, an existing measure of EF, would indicate relatively poor performance across both groups, relative to typically-developing peers. Conversely, findings reported for the alternating patterns test, an existing measure of EF, illustrate relatively strong performance across both groups, although it should be noted that normative data is not available for this measure and so findings are tentative in nature and should be interpreted with some caution. Indeed, because of the lack of data concerning the reliability or validity of the Brick Design Fluency, Box-light Test, Adapted Modified Weigl, and Tinkertoy Test measures, the results identified in this study must be treated with caution.

Summary of Secondary Findings

As has been highlighted in the results section of this paper, a number of significant correlations were identified in the data. Of note is the finding that increased verbal ability (BPVS) is associated with increased performance on the Adapted Modified Weigl and also on the NEPSY design fluency. One way of interpreting this data is to suggest that both the Adapted Modified Weigl and the NEPSY design fluency measures require good receptive verbal ability, possibly in understanding instructions. Moreover, the finding that increased performance on the Adapted Modified Weigl is associated with increased performance on the Tinkertoy Test Complexity score suggests that these measures may possibly be tapping the same functions. In interpreting the finding that increased non-verbal ability (RCPM) is inversely associated with increased performance on the Alternating Patterns Test, it might be suggested that the Alternating Patterns Test does not require non-verbal ability. It must be acknowledged however, that in light of the relatively small number of participants used, results must be interpreted with some caution.

Theoretical Implications

The findings presented do not fit with existing studies examining EF in autism that have identified EF deficits in individuals who have autism when compared to matched controls (e.g. Goldstein, Johnson & Minshew, 2001; Ozonoff & Jensen, 1999; Ozonoff, Pennington & Rogers, 1991). Given that the vast majority of studies have identified significant deficits in EF in both children and adults with autism when compared with control groups (Pennington & Ozonoff, 1996), this finding is not in line with the general consensus in the literature. However, a number of other studies have also failed to identify such differences (e.g. Minshew et al. 1992; Russell et al. 1999; Shu et al. 2001) and so it might be considered that whilst such differences are observed in the majority of the literature, they are not universal. Moreover, it must also be considered that this is one of a number of sub-components that make-up the profile of EF strengths/deficits observed in autism and as such it is possible that strengths or deficits may exist in other areas such as planning and organisation. However, it must be acknowledged that the methodological problems associated with this study make findings tentative in nature.

The results of this study do not fit with the assumption that children who have autism demonstrate deficits in cognitive flexibility as suggested by Pennington & Ozonoff (1996) since children were able to complete measures requiring cognitive flexibility. Moreover, these findings are not in line with studies that have identified perseverative errors in individuals who have autism (e.g. Rumsey & Hamburger, 1990). Using an existing measure that has been used to examine perseverative problems (the alternating patterns test: Lezak, 1995), children with autism showed no significant differences when compared to a matched control group. Moreover, both groups generally produced correct, non-perseverative responses. Despite the fact that ceiling effects have been show for this measure, it should be acknowledged that this measure is clinically used as an indicator of perseverative problems (Lezak, 1995) and as such, findings suggests that children in both groups did not show perseverative difficulties.

Existing researchers have suggested that EF may be an underlying cognitive impairment in autism, responsible for the behavioural symptoms observed (Russell, 1997), specifically cognitive flexibility (Pennington & Ozonoff, 1996). The findings of this study do not fit with this hypothesis in that, for EF to be an underlying impairment, it should be expected that EF deficits are universal to all individuals who have autism (Turner, 1997). This study has shown that a specific EF deficit in cognitive flexibility may not be universal to autism.

In testing the hypothesis presented in this study it has been necessary to develop a new battery of measures examining cognitive flexibility. Measures were selected and developed that it was felt would not be affected by impairments additional to

EF that are observed in autism (e.g. social and communication difficulties). Data obtained using this battery do not confirm existing findings in this field (e.g. Ozonoff et al. 1993). This finding has implications for the measurement of EF in children who have autism and learning disabilities. It has been suggested in the literature that measures used to assess EF such as the WCST and the TOH may tap multiple functions of EF (Pennington & Ozonoff, 1996) and may not be developmentally appropriate measures to use (Anderson, 1998). In identifying non-significant results using molar measures designed to isolate EF from memory, social and language ability, this study supports the argument that methodological problems associated with existing measures of EF must be taken into consideration when evaluating research examining EF in children who have autism (Pennington & Ozonoff, 1996).

This study follows the suggestion in the literature that studies should be undertaken using discrete EF measures, tapping sub-components of EF is required in order to more accurately identify the exact nature of EF deficits in autism (Pennington & Ozonoff, 1996). As such, this battery provides measures for a specific sub-component of EF that might be used alongside other measures of EF to develop EF profiles as suggested by Pennington and Ozonoff (1996).

Clinical Implications

The results identified in this study have a number of implications for the assessment of children who have autism. It has been suggested in the literature that EF measures might be useful in assessing the broader cognitive phenotype of autism (Bailey et al. 1996). This study did not find significant differences between the experimental and control groups using a battery of EF measures assessing cognitive flexibility and as such, does not support the use of these measures in the assessment of the phenotype. However, it is tentatively noted that a number of children in both groups showed specific deficits in cognitive flexibility whilst others showed fewer deficits in these areas, a finding which requires further validation from future studies. If properly validated, the measures used in this battery of tests may be useful tools for clinicians working with such children or developmentally delayed adults, who show problems with cognitive flexibility, for the assessment of such difficulties. Moreover, this battery might allow clinicians to examine profiles of specific sub-components of cognitive flexibility (i.e. creativity, perseveration and set-shifting). Such information would be critical in developing clinical formulations of a child's specific difficulties in order to then develop appropriate environmental adaptations or skills-teaching interventions and allocate necessary resources. However, given the floor and ceiling effects identified within this battery, further research may be required to modify measures for this ability group.

In addition to assessment procedures, the results of this study have a number of implications for the treatment of EF deficits in children who have autism. Despite an existing literature examining rehabilitation of EF in adults who have suffered head injuries (e.g. Levine et al. 2000), the literature reviewed makes few recommendations about the development of treatment protocols for EF deficits observed in autism. Intervention might therefore be in the form of adapted adult interventions such as those developed by Levine et al (2000), taking into consideration the developmental level of the child. Alternatively, intervention might entail environmental modifications aimed at structuring and organising the environment for the individual (Sohlberg et al. 1993). Indeed, structuring of the environment and careful planning of transitions is suggested as a key intervention in the literature for children who have autism (Howlin, 1998). However, it is also important when examining EF to consider how such cognitive deficits manifest in behaviour. Ozonoff (1995a) suggested that the behaviour of individuals who have autism is often rigid and inflexible, perseverative, impulsive, with individuals seemingly able to posses large stores of information, but not be able to use it correctly. It is suggested that such difficulties may be as a result of deficits in EF (Ozonoff, 1995a). Such behaviours might make a number of environments very challenging for a child with autism. For example, a classroom environment in which the child is required to shift between different activities several times during the day, stay seated for long periods of time and manipulate information, may be difficult to cope with. Thus, challenging behaviours may be displayed in response to such environments. Intervention may therefore be required that focuses on the behavioural consequences of deficits in EF. Applied Behavioural Analysis (ABA) deals with behavioural excesses and deficits by manipulating the environment systematically so that difficult behaviours are reduced through negative reinforcement whist wanted behaviours are taught and positively reinforced (Richman, 2001). ABA might therefore be used as a skills-teaching method, enabling children to learn how to respond to challenging situations appropriately. Indeed, skills-teaching is recommended within the adult neuropsychology literature for the rehabilitation of EF deficits (Sohlberg et al. 1993).

Methodological Issues

The range of measures selected and developed for this study is an attempt to create a battery that takes into account the behavioural and cognitive deficits observed in autism and as such, this is a pilot study in nature. However, the results of this study must be interpreted within the context of the methodology employed. Primarily, the selection of participants should be considered. Children were recruited from MLD schools on the basis of specific inclusion and exclusion criteria to control for individual differences in the sample. Each possible participant was evaluated using these criteria during an interview with head and class teachers from the schools used. Information concerning formal diagnosis of autism, learning disability, visual impairment, epilepsy or co-morbid disorders was obtained from school medical notes. Thus, this study is dependent on other professionals having made accurate diagnoses. Moreover, the need for conservative inclusion criteria produced problems in the recruitment of participants, decreasing the number of possible participants. As such, this study has a small sample and may not be representative of all children who have autism, particularly high-functioning and/or female children.

Existing measures chosen for this study (alternating patterns test, NEPSY design fluency and Tinkertoy test) differ in their levels of validity and reliability. Whilst the NEPSY design fluency has been shown to have modest reliability and acceptable interrater reliability (Korkman et al. 1998) and the Tinkertoy test has been shown to correlate significantly with other measures of EF such as the WCST (Mahurin et al. 1993), no data regarding reliability or validity could be identified for the alternating patterns test. As such, its validity as a measure of EF may be questioned. Moreover, the measures designed for this study have not been validated or normed and so data taken from them should be interpreted with some caution. Stemming from this issue is a difficulty in completing within-group analyses on the data, since normative data are unavailable for many of the measures.

In developing a series of measures, a number of specific issues have been raised in relation to the scoring of data. The box-light test relies on the examiner accurately assessing the number of button pushes that a child makes on each button. For example, to watch the child pushing the buttons, record the pushes in the appropriate place on the score form, and note any behavioural peculiarities displayed by the child, requires great concentration on the part of the examiner and may merit additional support such as the use of a video camera or a second rater present in the room. As such, the current recording system may be open to examiner error. Similarly, the brick design-fluency test requires careful evaluation by the examiner of the constructions made. In order to ensure accurate measurement, photographs were taken of the constructions and a scoring system was designed. Although the total similarities scoring system showed excellent inter-rater reliability, the sequential changes scoring system showed only fair inter-rater reliability, suggesting that further examination of the sequential changes scoring system may be required. For example, simplifying that language used for scorers might be beneficial. In addition, further training in the use of the scoring system might help to reduce examiner error. In scoring the names given to the constructions by children, a number of errors may also occur. For example, it is important to recognise that whilst the names given to brick design fluency objects by children may have differed in their language, they may have been conceptually similar. For example, one participant labelled three of his four models ‘a face’, ‘a happy face’ and ‘a sad face’. Although each is different to the next in its precise language they are all faces and so conceptually similar. The current scoring system might therefore be adapted to include an additional ‘conceptual similarity’ score.

Based on the principle of ‘behavioural momentum’, which suggests that positive and successful behaviour increases the likelihood of subsequent positive and successful behaviour (Ylvisaker & Fleeney, 1998) the order of tests was standardised, in that several relatively easy measures were presented before a harder measure. However, despite improving motivation, such a presentation does not account for order effects. Fatigue may be a problem in such presentations (Robson, 1993) in that poor performance on later measures is due to tiredness. However, when completing the last test in the battery (the Tinkertoy test) children were very motivated to complete the activity and performed to a reasonable level. Thus, this validates the use of the standardised procedure.

Inspection of the data illustrates that floor effects were present in the data for the NEPSY and Adapted Modified Weigl and that ceiling effects were present for the Alternating Patterns Test and the Box-Light Test. In interpreting this data, it must be considered that measures, although designed for this ability group, may have been too difficult in the case of the NEPSY and Adapted Modified Weigl and too easy in the case of the Alternating Patterns Test and the Box-Light Test, showing the difficulty of obtaining measures that are suitable for this ability range. As such, results taken from these measures have been omitted from the conclusions of this paper and must be interpreted with caution. However, it is important to recognise that for the Alternating Patterns Test (a recognised measure of perseveration), all children performed extremely well. Moreover, on the NEPSY, a standardised measure, used with children in this age and ability group, all children performed at a poor level.

Implications for Future Research

The interpretation of results with reference to existing research, and the methodological problems highlighted in the design utilised by this study, illustrate a number of issues which should be addressed within future research. Firstly, the need for properly normed and validated measures of EF for children has been highlighted in the literature (Anderson, 1998) a lack of which makes interpretation of data difficult. As such, the findings of this study are largely between-group differences rather than within-group individual differences. A future study might aim to incorporate an age-matched sample of typically developing children to this data set, thus providing normative data and comparison with peers of typical development. Moreover, in order to undertake an examination of the reliability and validity of the measures developed, future studies might obtain a large normative sample of children with the inclusion of female participants. Such studies might also allow clinical cut-off scores to be developed, thus allowing future analysis to examine, within groups, the percentage of participants either passing or failing a measure. An integral part of such research, might be to examine correlations between measures of EF, identifying the extent to which newly developed measures (e.g. brick design fluency) are related to existing EF measures (e.g. NEPSY design fluency) and also between measures of EF and intelligence, identifying the extent to which measures might be related to either verbal or non-verbal ability.

The dependence of many studies of EF on measures such as the WCST has been questioned within the literature, especially when they are used with child populations (Pennington & Ozonoff, 1996; Anderson, 1998). In addition, there may be a need to consider the nature of autism when considering tests. This study has attempted to develop a battery of measures that account for the deficits and skills observed in children who have autism and learning disabilities. Future research is urgently required that examines the validity of existing measures of EF for children who have autism and is aimed at developing new measures that take into account issues of development and autism as well as learning disabilities. For example, the possible ceiling and floor effects identified in this study suggest a need for measures that are carefully matched to the ability level of participants. Moreover, the need for further molar EF measures, assessing other sub-components of EF in order to develop EF profiles (Griffith et al 1999, Ozonoff & Pennington, 1996) should be an area of future research.

Participant selection has been highlighted as a methodological problem faced in this study. Future studies in this field might therefore seek to incorporate a more comprehensive assessment in relation to inclusion and exclusion criteria. For example, the use of an autism behaviour checklist (e.g. Autism Screening Questionnaire: ASQ: Berument, Rutter, Lord, Pickles & Bailey, 1999) would provide additional data to support or refute a child's diagnosis of autism. Such data might also then be correlated with performance on measures of EF to examine whether EF performance is related to symptoms of autism.

The preliminary scoring system devised for the Brick Design Fluency test sequential changes score has been shown in this paper to have only fair inter-rater reliability. As such, a future research project might aim to develop a more accurate scoring system for this measure. Similarly, the scoring system for the box-light test is made difficult by the experimenter having to watch both the child and a score sheet simultaneously. It has been suggested that for individuals who demonstrate social avoidance (as is observed in autism), the elimination of social interaction in computerised tests may aid performance (Ozonoff, 1995b). Future administration and scoring systems might therefore be developed that use computers, thereby reducing experimenter error and allowing more accurate measurement. For example, measures such as the box-light could be easily adapted for a computer to record the button presses made by the child. Alternatively, video-taped assessments examined at a later date might provide a more accurate scoring method.

Although experimentally validated rehabilitation protocols for deficits in EF are minimal (Levine et al. 2000) therapeutic approaches such as: environmental modification (e.g. providing structure) and specific-skills training (e.g. using cues, behaviour modification and metacognitive skills) have been suggested (Sohlberg, Mateer & Stuss, 1993). Furthermore, recently researched protocols have been developed such as 'Goal Management Training' (Levine et al. 2000) which seeks to encourage goal-directed behaviour using a series techniques designed to help the individuals to orient to a goal, set a goal, partition a goal into subgoals, and retain and monitor the subgoals. Despite existing protocols that are available for the management of different sub-components of EF, as yet no studies have been reported that apply this methodology to children who have autism, who are reported in the literature to demonstrate specific EF deficits. Given that it is acknowledged that early intervention is critical in autism (Howlin, 1998) future research is urgently required that examines possible treatments for the EF deficits observed. A secondary area that has as yet not been addressed in the literature is the extent to which existing treatment protocols for children who have autism, may help children to overcome any possible EF deficits. For example, The Treatment and Evaluation of Autistic and related Communication handicapped Children (TEACCH) approach (Schopler, 1997) incorporates a number of environmental adaptations that help children to stay focused and engaged on a task but that also require minimal planning, organising and flexibility from the child. Given that such systems may require fewer EFs than would a normal class routine, it is possible that the environmental adaptations of such systems may actually serve a rehabilitative or coping function for children with EF deficits. Future research might therefore examine the extent to which existing environmental adaptations may help children with autism to overcome EF deficits. Furthermore, intervention strategies such as TEACCH have a tendency to be used in autism populations. However, there may be a need for it to be used in other populations such as in children who have learning disabilities. Clinically, such strategies are also used with children who do not have autism. Future research might therefore examine why it is that those children who do not have autism, but use systems such as TEACCH, benefit from it. For example, studies might examine whether TEACCH helps these children cope with possible deficits in EF.

Conclusions

In summary, this study examines EF in children who have autism using measures designed specifically to assess cognitive flexibility. Although a number of the measures have been shown to have floor effects (the NEPSY design fluency and the Adapted Modified Weigl) and ceiling effects (the Alternating Patterns Test and the Box-Light Test), it is illustrated that for remaining measures (the TinkerToy Test and the Brick Design Fluency test) group differences were not identified. This is an interesting finding as it does not fit with much existing research examining EF in children with autism, which has typically identified EF deficits in this population, particularly with reference to cognitive inflexibility. As an underlying cognitive deficit, EF theory provides a useful way of conceptualising the deficits observed in autism and can be used to explain many associated behaviours. This study highlights that further research is urgently required that critically examines the methods used to evaluate this theory, integrating knowledge from the fields of autism, learning disabilities, neurospychology and child development.

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Table 1: Participant Characteristics: Chronological age, raw scores for the British Picture Vocabulary Scale (BPVS) and Raven's Coloured Progressive Matrices (RCPM) and Verbal Mental Age (VMA) as measured by the BPVS.

Group	n		Chronological age (years)	BPVS Raw score	BPVS VMA (years)	RCPM* Raw score
Autism	12	M	9.51	58.75	5.75	22.08
		SD	1.70	15.32	1.52	8.45
		Range	(6.58-11.67)	(36-89)	(3.5-8.75)	(12-35)
MLD	11	M	8.93	58.45	5.71	17.27
		SD	1.75	14.79	1.45	5.20
		Range	(6.25-12.67)	(43-84)	(4.17-8.17)	(9-26)

* Because a number of the scores for the RCMP fell above and below the available norms, NVMA could not be calculated for the groups. However, the mean raw score for both groups falls within the Ravens Grade IV range for "Definitely below average in intellectual capacity".

Table 2. Descriptive statistics for all measures for experimental and control groups.

Scores for EF Measures	Autism			Control			
	M	SD	Range	M	SD	Range	Range possible on measure
Modified Weigl	2.17	2.76	0-8	2.91	1.87	0-6	0-12
Brick design fluency sequential changes	15.82	4.45	9-21	15.82	4.31	9-21	0-24
Brick design fluency total similarities	10.09	4.30	3-18	10.36	3.26	7-15	0-24
Nepsy design fluency test	5.44	2.19	1-9	5.64	2.98	1-11	0-35
Tinkertoy test complexity score	5.73	2.28	2-10	6.09	1.14	4-7	<-1-12
Tinkertoy test creativity score	1.09	0.70	0-2	1.00	0.63	0-2	0-3
	Mode	Range		Mode	Range		
Box-light test pattern 1	1	1-2		1	1-1		1-3
Box-light test pattern 2	1	1-3		1	1-3		1-3
Box-light test pattern 3	1	1-3		1	1-3		1-3
Alternating patterns test	1	1-3		1	1-3		1-3

Appendices

Appendix 1 Autism Battery of Cognitive Flexibility

The Autism Battery of Cognitive Flexibility

Record Form

Name	
Gender	
Hand preference	
First language	
School	
Teacher	

	Year	Month	Day
Date test started			
Date of birth			
Age at time of testing			

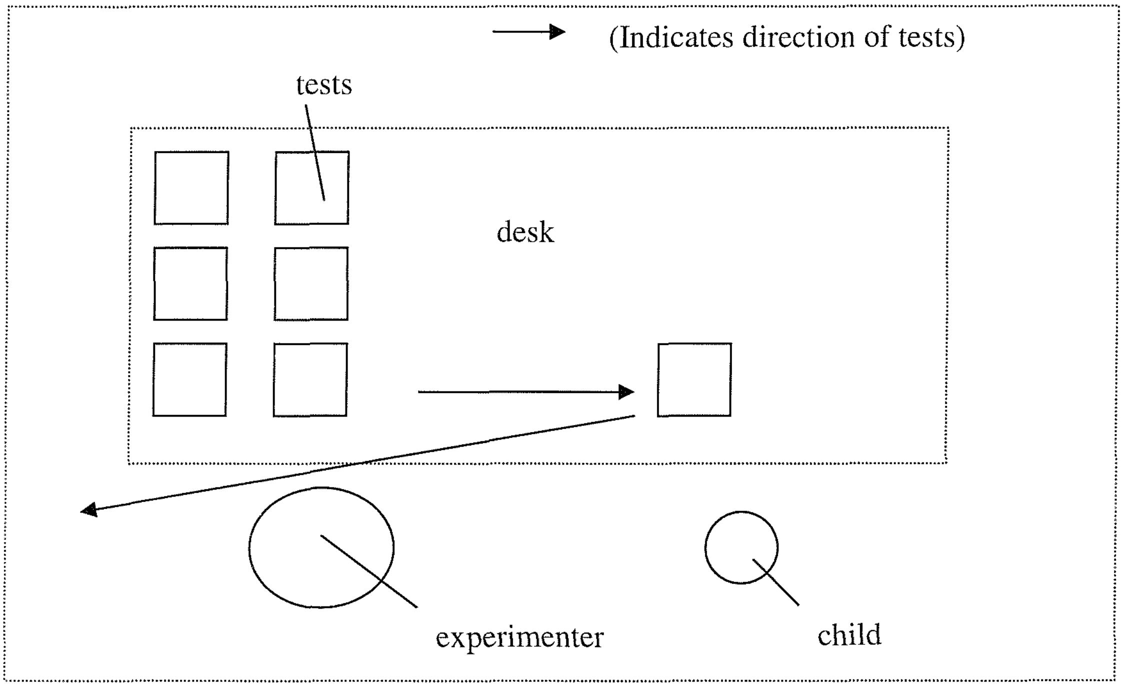
Place of testing	
Time of testing	

Test	Administered? (please tick)	Page Number	Score
1: BPVS		separate score sheet	
2: Ravens		separate score sheet	
3: Box-light test		6	
4: Adapted Modified Weigl		7	
5: Alternating pattern test		8	
6: Brick design fluency	Part a:	9	
	Part b:	10-11	Sequential= Total=
7: Design fluency		12	
8: Tinkertoy test		13	

Administration

Presentation:

Each test will be presented in one of eight coloured boxes that will be presented at the left side of the desk (see below). As each test is used, it is placed in front of the child. When it is completed it is placed to the left of the desk to show that it is finished.



Pre-testing procedure:

1. Agree a set time with the teacher for the child to be tested. Ensure that the child knows s/he is going to be tested and is reminded about it.

2. Ensure each test is presented in the standardised way in the room before the child is collected.

2. Take a few minutes to meet the child with teacher in classroom to ensure s/he is comfortable and to develop some rapport. Explain that *"We are going to do some puzzles in another room and that when we finish we will come back to the classroom."*

Administration:

1. Spend a few minutes in the room explaining to the child clearly what it to be done. Say to the child, *"We are going to do 1,2,3,4, 5, 6, 7, 8 puzzles* (point to each box) *and then we will finish and we will go back to the classroom. If you want to stop them tell me so."*

2. Begin the first test only when the child is happy to continue.

3. Complete the tests in the agreed order and format as specified in the administration instructions. Two symbols are used in the text: ☞ indicates an action or prompt to be made by the examiner whilst 🗣 indicates a verbal instruction to be made by the examiner.

4. When each test is finished it should be put in its box and set to one side to show that it is completed (this is illustrated in the presentation diagram).

5. Monitor the child carefully for signs of distress and keep checking out that s/he is OK to continue.

6. When the child has completed all of the tests, or it is necessary to stop testing because the child is distressed, tell the child that s/he has done really well to complete the tests. Go back to the classroom with the child and 'hand-over' to teacher.

7. If it is necessary to continue testing at a later time (e.g. because the child became distressed), use the same instructions as before, but change the number of tests accordingly (e.g. *"We are going to do 1,2,3 tests."*).

British Picture Vocabulary Scale

☞ Training plates A and B are for under 8's.
🗣 *"Put your finger on/ point to..."*

☞ Training plates C and D are for over 8's.
🗣 *"What number is/ point to..."*

☞ Check what age the child is and start with the appropriate set.

☞ Basal set = no more than one error
Ceiling set = eight or more errors

☞ Record responses on BPVS scoring sheet

Ravens Coloured Progressive Matrices

☞ Show the child **A1**
🗣 *"Look at this. Only one goes in here. Which one of these goes in here?"*
☞ If the child does not understand, continue to explain until the nature of the problem is clearly grasped.

☞ Show the child **A2**.
🗣 *"Look at this. Only one goes in here. Which one goes in here?"*
☞ If child does not understand, re-demonstrate using A1 again until child understands.

☞ Show the child the remaining puzzles.
🗣 *"Look at this. Only one goes in here. Which one goes in here?"*

☞ Record responses on RCPM scoring sheet

Box-light test

*(L=Left, R=Right)
Correct= as done by the experimenter, *Incorrect*= random, *Perseverative*= Stuck on a repetitive incorrect pattern or a previous pattern for more than **six** pushes of the buttons.

Trial 1:

- Place the box directly in front of the child
- *"This is what I want you to do."*
- Press the buttons: L,R,L,R,L,R* (move hand away from button after press)

- *"Now you try. Keep going"*
- Time 20 seconds
- *"Stop"*

Note child's responses

Score: Correct / Incorrect (random) / Perseverative

Trial 2:

- *"This is what I want you to do."*
- Press the buttons: L,R,R,L,R,R,L,R,R
- *"Now you try. Keep going"*
- Time 20 seconds
- *"Stop"*

Note child's responses

Score: Correct / Incorrect (random) / Perseverative

Trial 3:

- *"This is what I want you to do."*
- Press the buttons: R,L,L,R,L,L,R,L,L
- *"Now you try. Keep going"*
- Time 20 seconds
- *"Stop"*

Note child's responses

Score: Correct / Incorrect (random) / Perseverative

Adapted Version of the Modified Weigl

☞ Place the test in front of the child (ensure pieces are mixed-up).

🗣 *"This is a sorting game."*

🗣 *"Can you sort these out? Which ones go together? Can you show me which ones go together?"*

☞ If child does not understand show them a difference in the pictures (dogs, clocks, bees and trumpets).

☞ Score pass if correct, fail if an error is made in the sort or if the sort is an incorrect characteristic (e.g. contrary to the instruction).

🗣 *"Can you do it in a different way? Can you do it another way?"*

☞ If child does not understand show them change from picture to shape.

🗣 *"Can you do it a different way?"*

Trial	Correct sort? Y/N	Sort type	Score
1			
2			
3			
4			
5			
6			

Possible sort types: Colour (Red, yellow, blue, green)
Shape (squares, triangles, circles)
Thickness (thick, thin)
Size (small, large)
Pictures (instruments and animals)
Pictures (clocks, dogs, bees, trumpets)

Scoring: Score for each failed sort and 2 for each successful sort.

Alternating Patterns Test

☞ Place the test copy between the examiner and the child.
🗣 *"Do you see this line? It has a pattern to it. I would like you to continue the pattern, like this.*
☞ Continue the pattern for ten seconds. Move paper away from child.

☞ Place the experimental copy in front of the child.
🗣 *"Draw the line and keep going until I tell you to stop."*
☞ Start timing (allow one minute)
🗣 "Stop"

☞ If the child cannot understand the task, use the test copy to give further examples.

Correct= as demonstrated in the example, *Incorrect*= random, *Perseverative*= Stuck on a repetitive incorrect pattern for more than three objects (e.g. three squares in a row).

Score: Correct / Incorrect (random) / Perseverative

Brick Design Fluency Test
Part a. Picture Differences Test

🗣 *"Before we do the next puzzle, I have some pictures to show you."*

Trial 1:

☞ Show pictures 1 and 2 (different).
🗣 *"Are these the same or are they different?"*

Correct?	**Y**	**N**

🗣 *"How are they different/ the same?"*
Note child's response

Trial 2:

☞ Show pictures 1 and 1 (same).
🗣 *"Are these the same or are they different?"*

Correct?	**Y**	**N**

🗣 *"How are they different/ the same?"*
Note child's response

Brick Design Fluency Test
Part b. Brick Design Fluency Test

- 🗣 *"Can you make me something with these bricks?"*
- ☞ Move construction to back of testing area when complete.
- 🗣 *"That's really good. Now can you make me something different?"*
- ☞ Continue for all four trials.
- ☞ Take a photograph of the constructions at the end of testing.

Ability:

0 = 'Could not complete task'
1 = 'Could complete task with some difficulty' (i.e. made
2 = 'Could complete task with ease'

Trial	Score
1	
2	
3	
4	

Name given to object by child:

Trial	Name	Change? Y / N
1		
2		
3		
4		

Brick Design Fluency Scoring System

Sequential changes scoring system

	2 (compared to 1)	3 (compared to 2)	4 (compared to 3)
Change?	Y=1 / N=0	Y=1 / N=0	Y=1 / N=0
Name change?	Y=1 / N=0	Y=1 / N=0	Y=1 / N=0
Change in height?	Y=1 / N=0	Y=1 / N=0	Y=1 / N=0
Change in width?	Y=1 / N=0	Y=1 / N=0	Y=1 / N=0
Change in Depth?	Y=1 / N=0	Y=1 / N=0	Y=1 / N=0
Persisting features:			
Triangle	Y=0 / N=1	Y=0 / N=1	Y=0 / N=1
Semi-circle	Y=0 / N=1	Y=0 / N=1	Y=0 / N=1
Bridge	Y=0 / N=1	Y=0 / N=1	Y=0 / N=1
Total score =			

Total similarities scoring system

	Insert score	
How many identical designs are there? (out of 4)		-1=
How many identical names are there? (out of 4)		-1=
How many identical heights are there? (out of 4)		-1=
How many identical widths are there? (out of 4)		-1=
How many identical depths are there? (out of 4)		-1=
Persisting features:		
How many times is a triangle a in the same place? (out of 3)		
How many times is a semi-circle in the same place? (out of 3)		
How many times is a bridge in the same place? (out of 3)		
Total score=		

NEPSY Design Fluency

Random Array:

☞ Present the Random array teaching example and say:

🗣 *"Here are some boxes with dots. I want you to connect two or more using straight lines, to make a design in each box. Make sure that each design is different from the others. Let's practice."*

☞ Draw a line connecting two dots within the first box.

🗣 *"Now you do these, making sure every design is different."*

Have the child produce different designs on the remaining three boxes. Explain any errors. When the child has correctly completed the teaching example, turn to the random array (positioned horizontally with arrows pointing away from the child).

🗣 *"In every box, connect two or more dots with straight lines. Work as quickly as you can, and make every design different. Start here. Ready? Begin."*

Scoring: Count the number of designs for each item. Remember, to include only unique, correct designs; repetitions of a design should not be counted.

Design fluency random array score	

Tinkertoy Test

- Place the 50 pieces in front of the child.
- *"Make whatever you want with these. You will have at least five minutes and as much more time as you wish to make something."*
- Start timing the child.
- If the child cannot start spontaneously, prompt him by taking one piece and connecting it with another.
- *"You see. The pieces fit together. Now you try. Make whatever you want."*
- Start timing the child.

When the child has finished (allow at least 5 minutes of time) take a photograph and place the object to one side.

Complexity Score

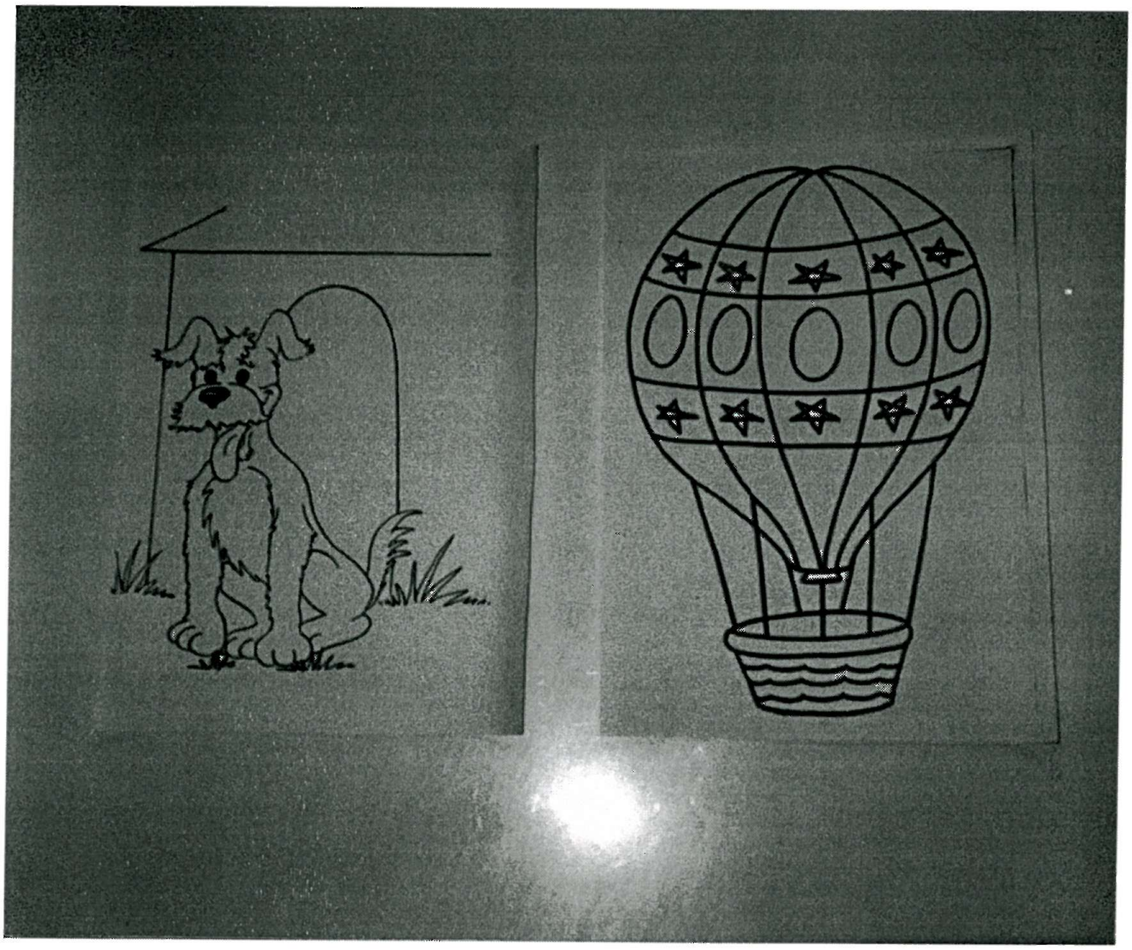
Variable	Scoring criteria	Points	Score
1. *mc*	Any combination of pieces	1	
2. *nc*	n<20=1, <30=2, <40=3, <or=50=4	1-4	
3. *name*	appropriate=3,vague/inappropriate=2, post hoc naming,description=1, none=0.	0-3	
4. *mov*	Mobility=1, moving parts=1	0-2	
5. *3d*	3-dimensional	1	
6. *stand*	Free-standing, stays standing	1	
7. *error*	For each error, misfit, incomplete fit, drop and not pick up.	-1	
			Total

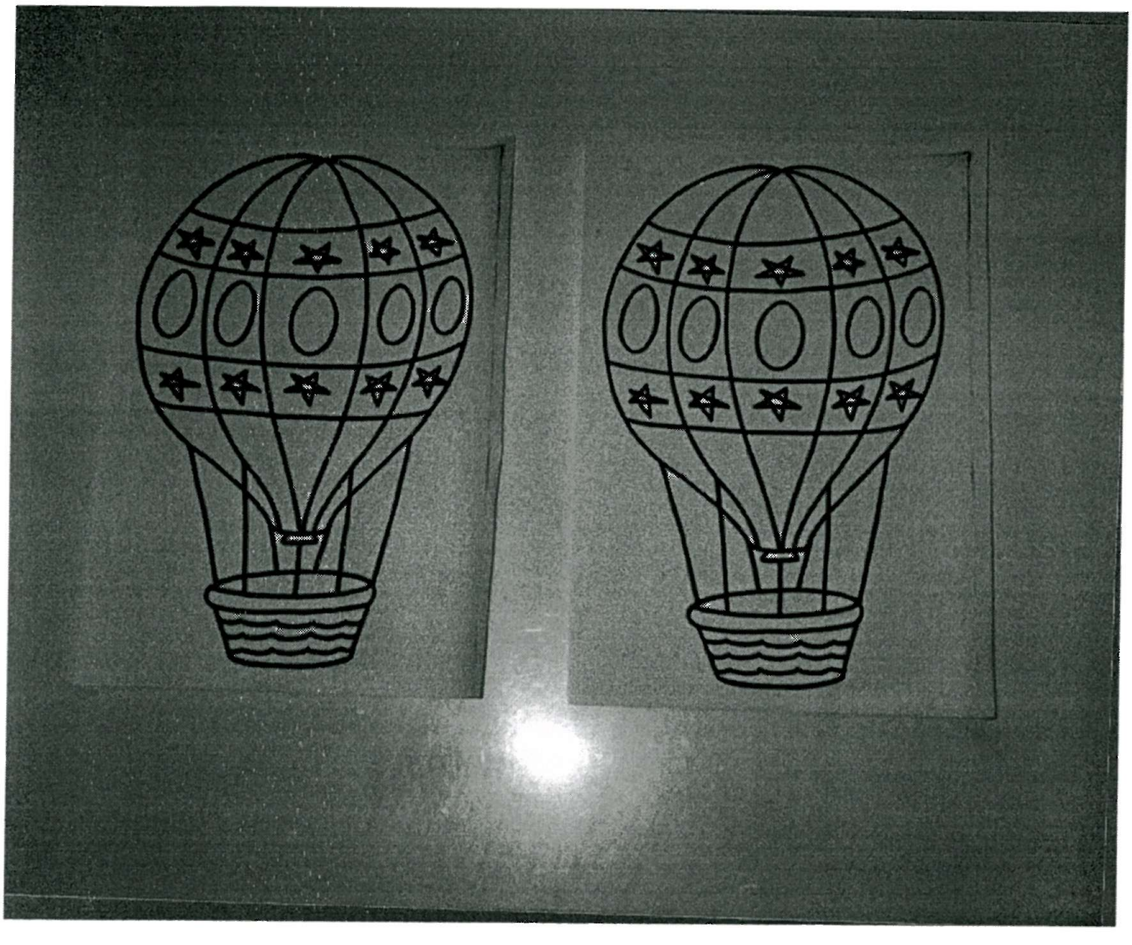
Creativity Score

Scoring Criteria	Points	Score
No name or inappropriate	0	
Real object, pieces = or < 30	1	
Real object, pieces > 30	2	
Imaginary/ abstract, pieces = or < 30	2	
Imaginary/ abstract, pieces > 30	3	
		Total=

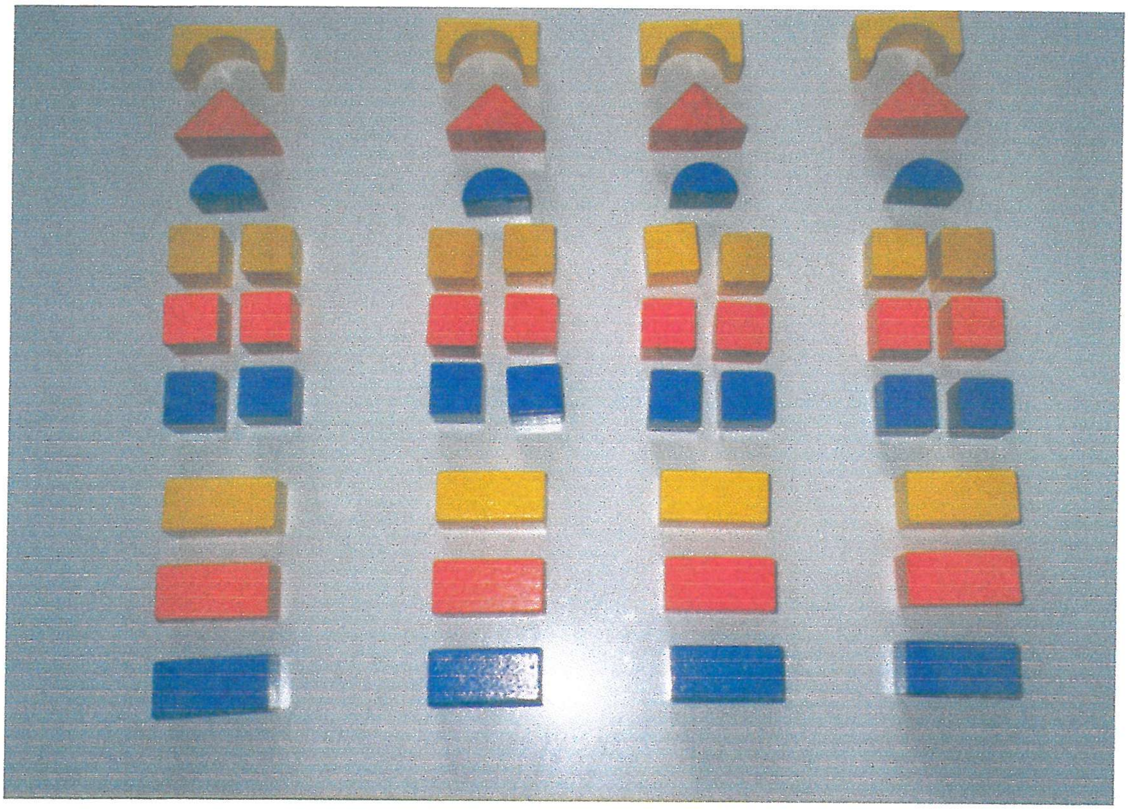
Score for complexity	
Score for Creativity	
Name given to object by child	

Appendix 2 Picture of brick design fluency test: Part A

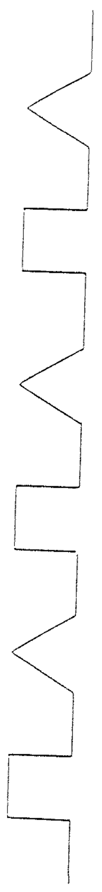




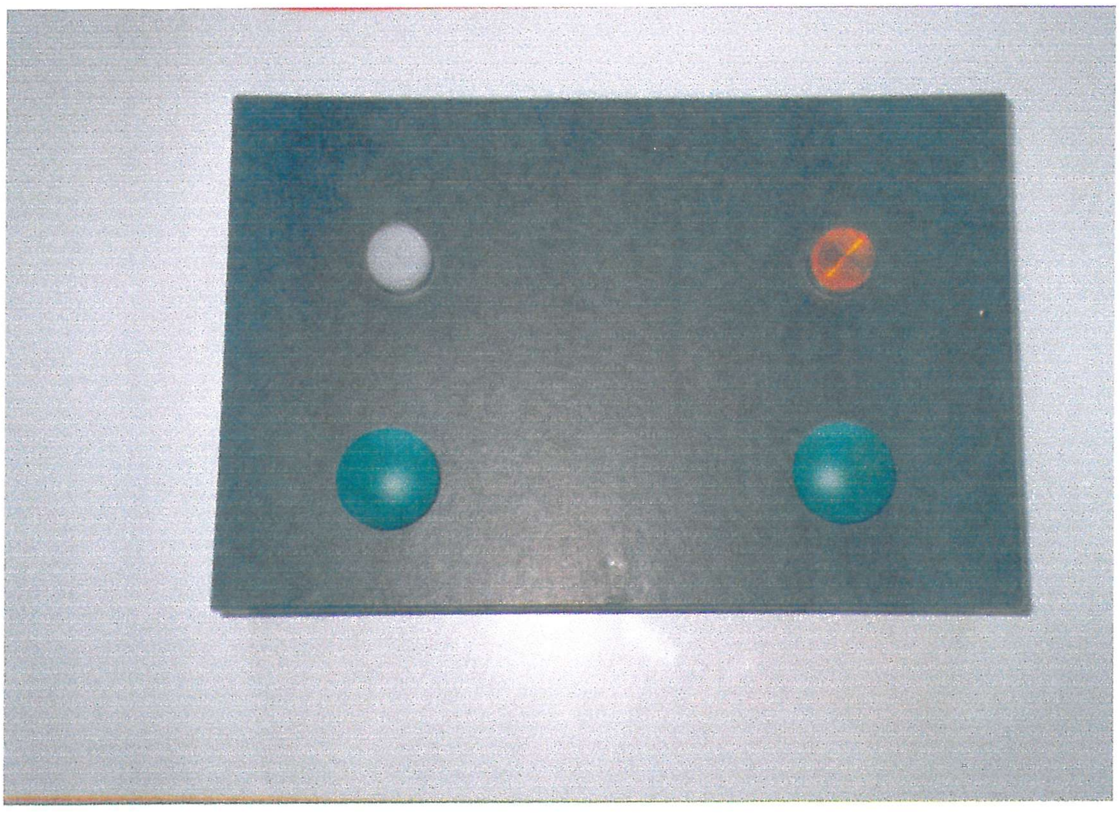
Appendix 3 Picture of brick design fluency test: Part B



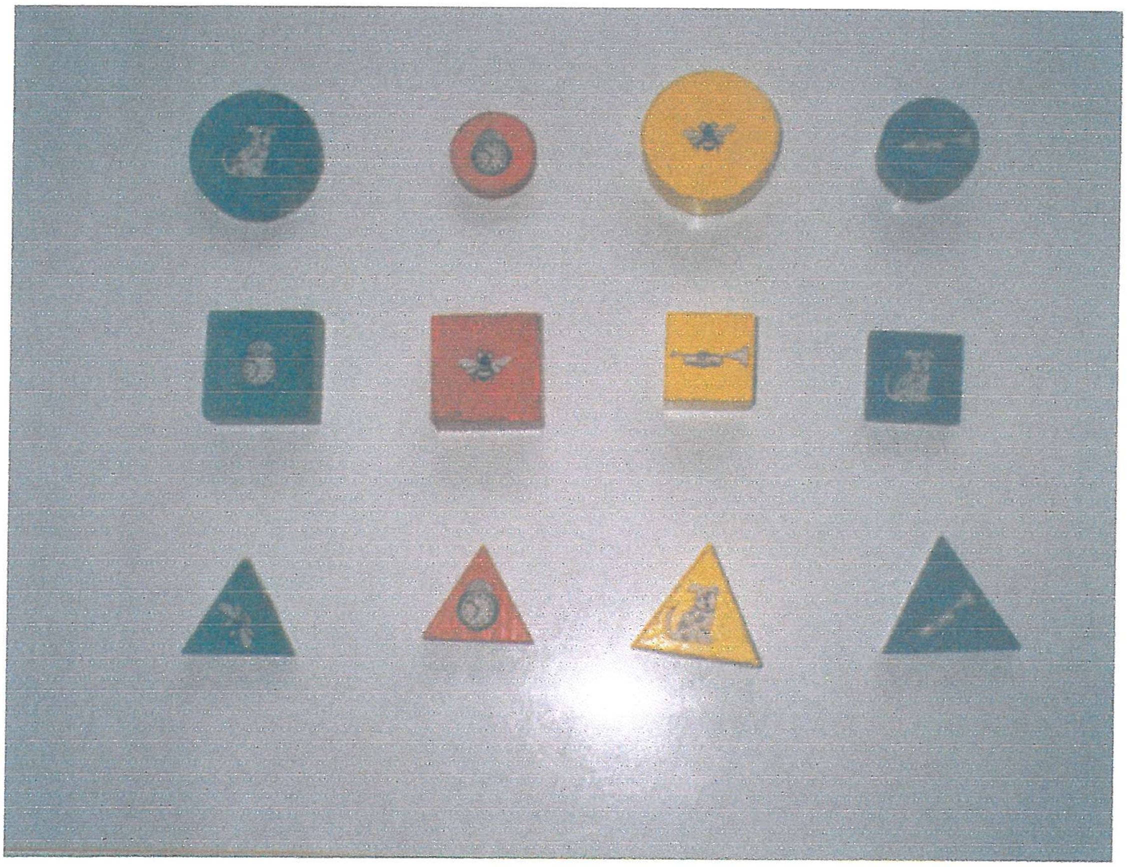
Appendix 4 Alternating patterns test stimulus sheet



Appendix 5 Picture of box-light test



Appendix 6 Picture of adapted version of the modified Weigl



Appendix 7 Ethical approval from Southampton University

University of Southampton

Department of Psychology

University of Southampton
Highfield
Southampton
SO17 1BJ
United Kingdom

Telephone +44 (0)23 8059 5000
Fax +44 (0)23 8059 4597
Email

12 March 2002

Mr Ben Rogers
Department of Clinical Psychology
University of Southampton
Highfield, Southampton

Dear Ben,

Re: Executive function in children who have autism and moderate learning disabilities: A critical analysis of the executive dysfunction hypothesis of autism

The above titled application, which was recently submitted to the departmental ethical committee, has now been given approval.

Should you require any further information, please do not hesitate in contacting me on 023 8059 3995.

Yours sincerely,

Kathryn Smith
Ethical Secretary

cc. Janet Turner

Appendix 8 Information sheet and consent form

(ON HEADED PAPER)

Dear Parent/ Guardian (of autism participants),

Information regarding a clinical research study investigating executive function in children who have autism

As part of my doctoral programme in Clinical Psychology, I am conducting a research study that looks at executive function in children who have autism. Executive function can be described as higher cognitive functions such as planning, organising and flexible thinking. This study is to examine whether the flexible thinking of children who have autism is different from that of children who do not have autism.

Your son will enable us to understand better the executive functions of children who have autism. This information will help the Psychology service to develop methods of working with children who have autism and will provide your son's teachers with new ways of working with him.

I am writing to you to inform you about this research study and ask if you would be prepared to give your permission for your child to be included in the study. If you allow your child to participate, he will be given eight short puzzles. The puzzles examine a range of non-verbal and verbal abilities and will require him to complete tasks such as building an object with bricks, and sorting some objects by shape or colour.

Permission for involvement in this study can be withdrawn at any time. Withdrawal from the project would not require justification. Participation in this study would be anonymous and a copy of the findings would be made available for your information.

I would be most grateful if you would give your permission for your child to participate in this study by signing and returning the enclosed consent form.

If you require any further information or have any questions or queries, please do not hesitate to contact me.

Thank you for your co-operation.

Ben Rogers
Trainee Clinical Psychologist
Doctoral Programme in Clinical Psychology
University of Southampton

Dr Tony Brown
Chartered Clinical Psychologist
Doctoral Programme in Clinical Psychology
University of Southampton

(ON HEADED PAPER)

Dear Parent/ Guardian (of control participants),

Information regarding a clinical research study investigating executive function in children who have autism

As part of my doctoral programme in Clinical Psychology, I am conducting a research study that looks at executive function in children who have autism. Executive function can be described as higher cognitive functions such as planning, organising and flexible thinking. This study is to examine whether the flexible thinking of children who have autism is different from that of children who do not have autism.

Your son will enable us to understand better the executive functions of children who do not have autism. This information will help the Psychology service to develop methods of working with children and will provide your son's teachers with new ways of working with him.

I am writing to you to inform you about this research study and ask if you would be prepared to give your permission for your child to be included in the study. If you allow your child to participate, he will be given eight short puzzles. The puzzles examine a range of non-verbal and verbal abilities and will require him to complete tasks such as building an object with bricks, and sorting some objects by shape or colour.

Permission for involvement in this study can be withdrawn at any time. Withdrawal from the project would not require justification. Participation in this study would be anonymous and a copy of the findings would be made available for your information.

I would be most grateful if you would give your permission for your child to participate in this study by signing and returning the enclosed consent form.

If you require any further information or have any questions or queries, please do not hesitate to contact me.

Thank you for your co-operation.

Ben Rogers
Trainee Clinical Psychologist
Doctoral Programme in Clinical Psychology
University of Southampton

Dr Tony Brown
Chartered Clinical Psychologist
Doctoral Programme in Clinical Psychology
University of Southampton

(ON HEADED PAPER)

CONSENT FORM

Executive function in children who have autism

Participants full name: ....

Parent/ Guardian full name: ....

Please complete the following:

Please circle as necessary

Have you read the information sheet?	Yes / No
Have you had an opportunity to ask questions and discuss this study?	Yes / No
Have you received satisfactory answers to all your questions?	Yes / No
Have you received enough information about the study?	Yes / No

Who have you spoken to? ....

Do you understand that you are free to withdraw from this study:

- At any time
- Without having to give a reason for withdrawing.
- Without affecting your child's future education. Yes / No

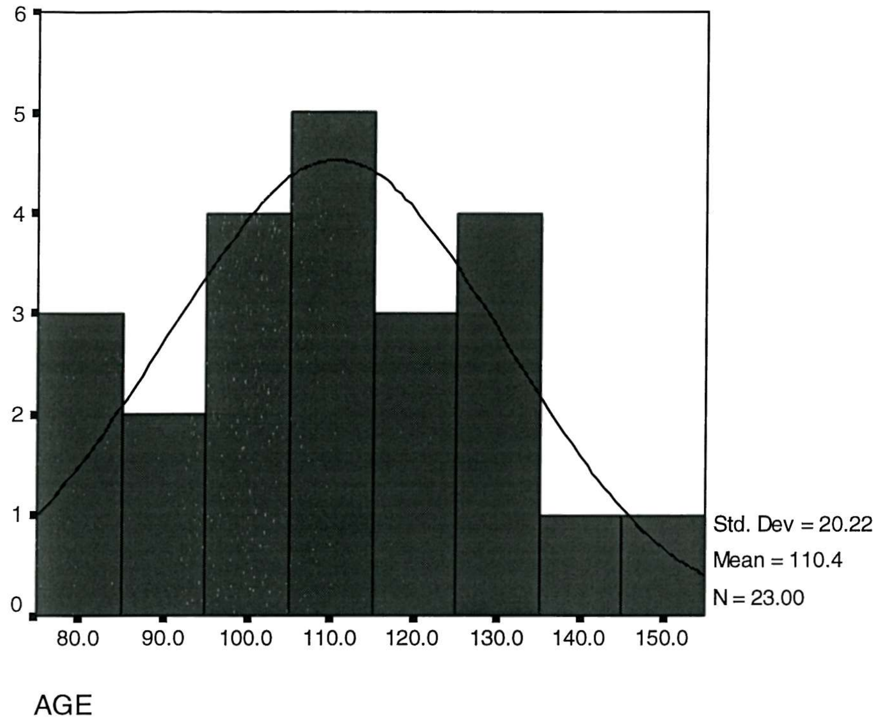
Do you agree for your child to take part in this study? Yes / No

I.. HEREBY CONSENT for my child, as named above, to take part in a clinical research investigation about which I have received written information.

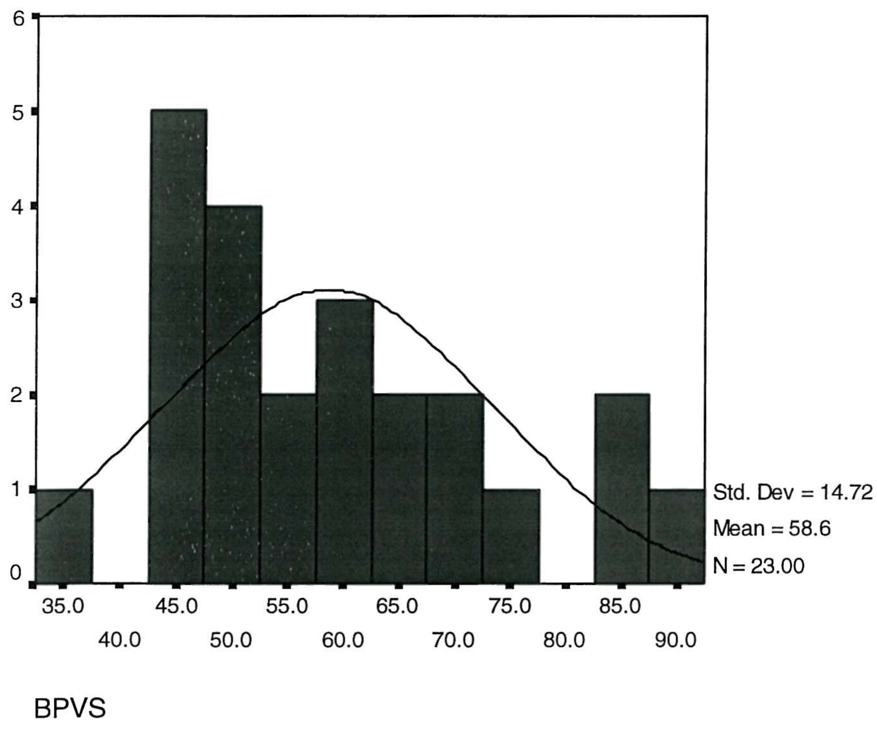
Signed:______________________________________ Date:______________

Appendix 9 Histogram plots illustrating the distribution of data

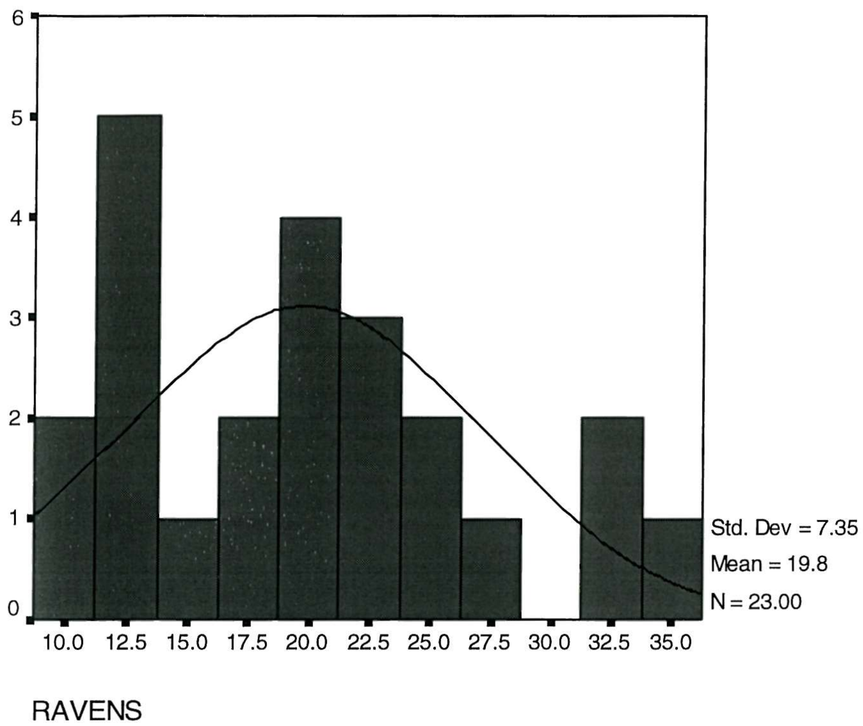
Graph 1: Histogram plot showing distribution of data for Age



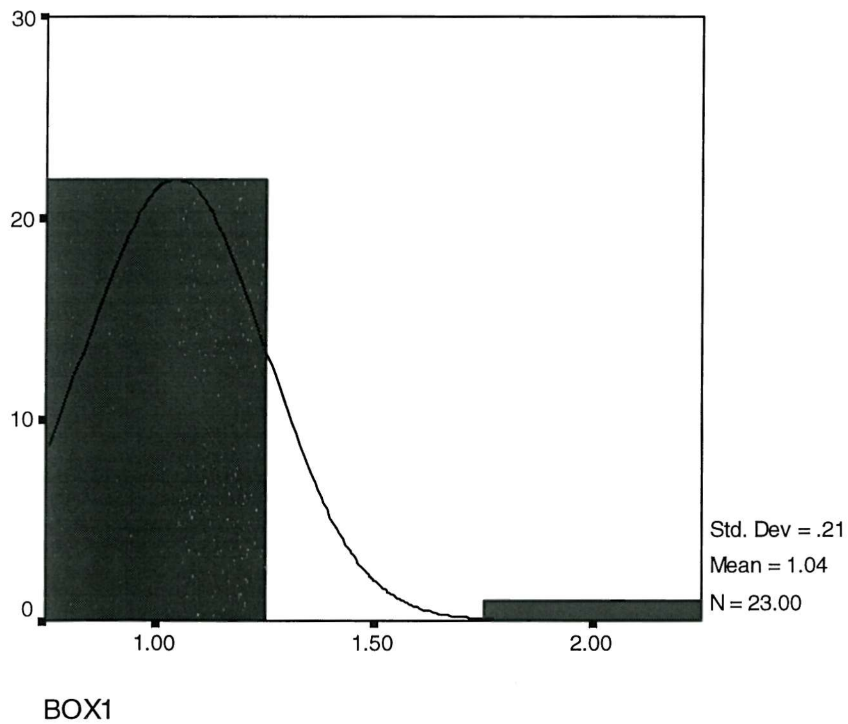
Graph 2: Histogram plot showing distribution of data for BPVS



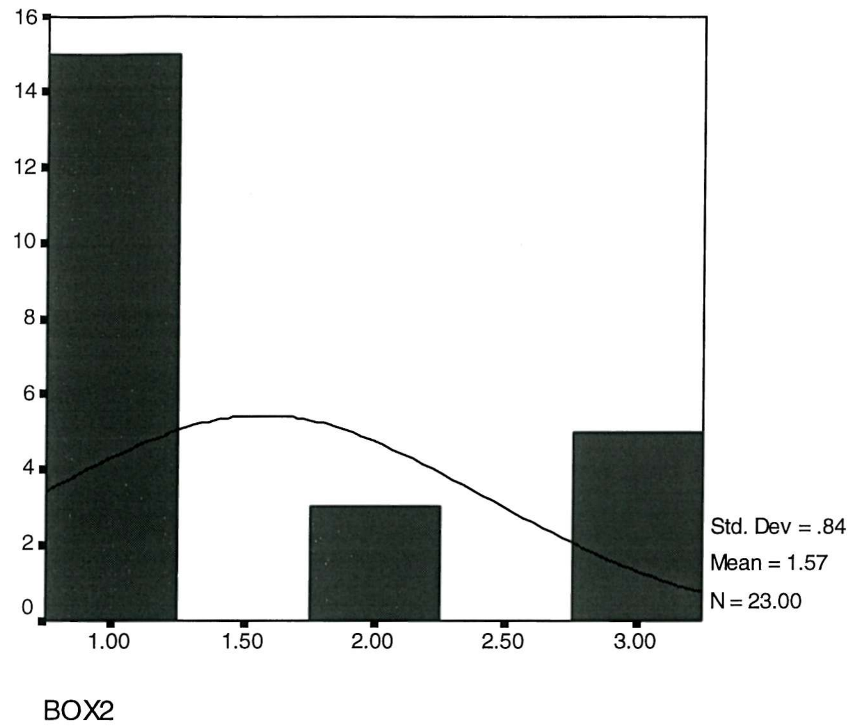
Graph 3: Histogram plot showing distribution of data for the RCPM



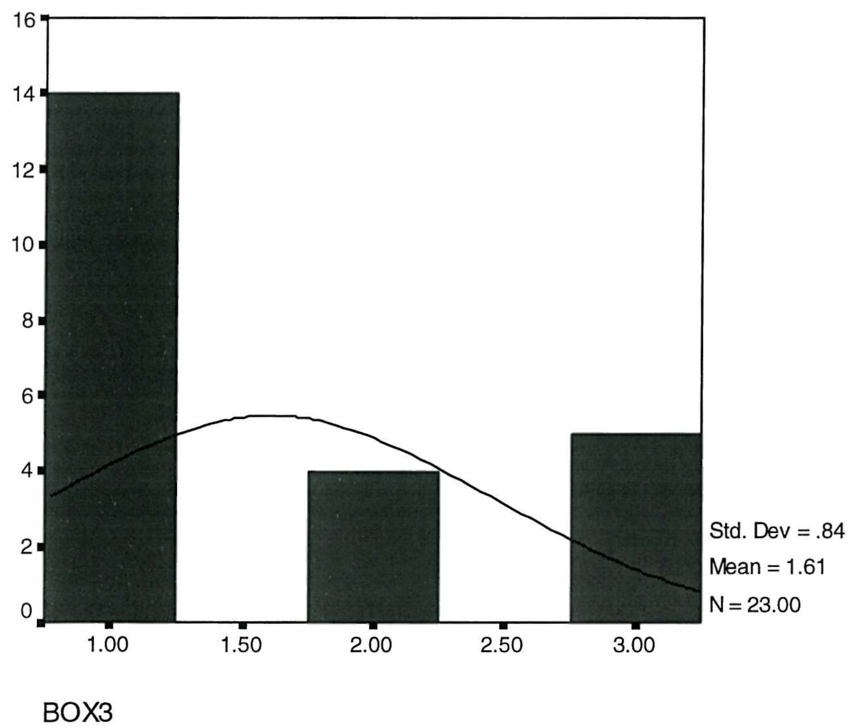
Graph 4: Histogram plot showing distribution of data for box-light test pattern 1



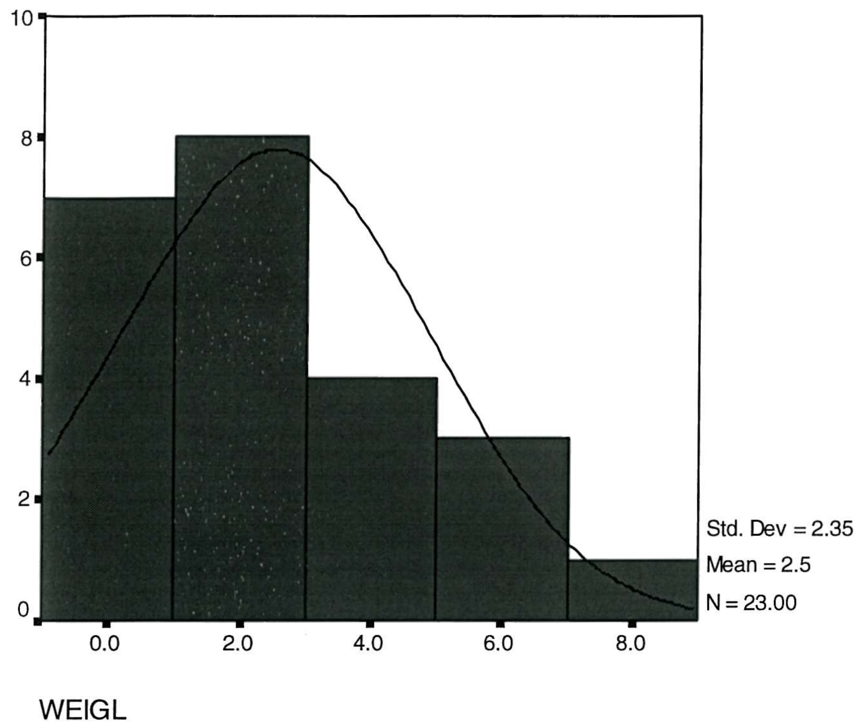
Graph 5: Histogram plot showing distribution of data for box-light test pattern 2



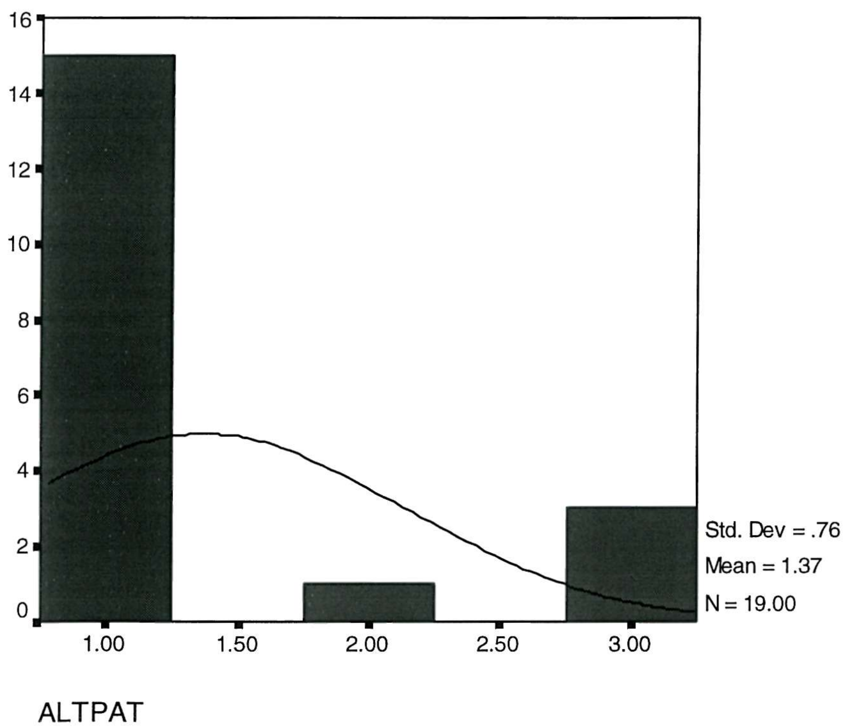
Graph 6: Histogram plot showing distribution of data for box-light test pattern 3



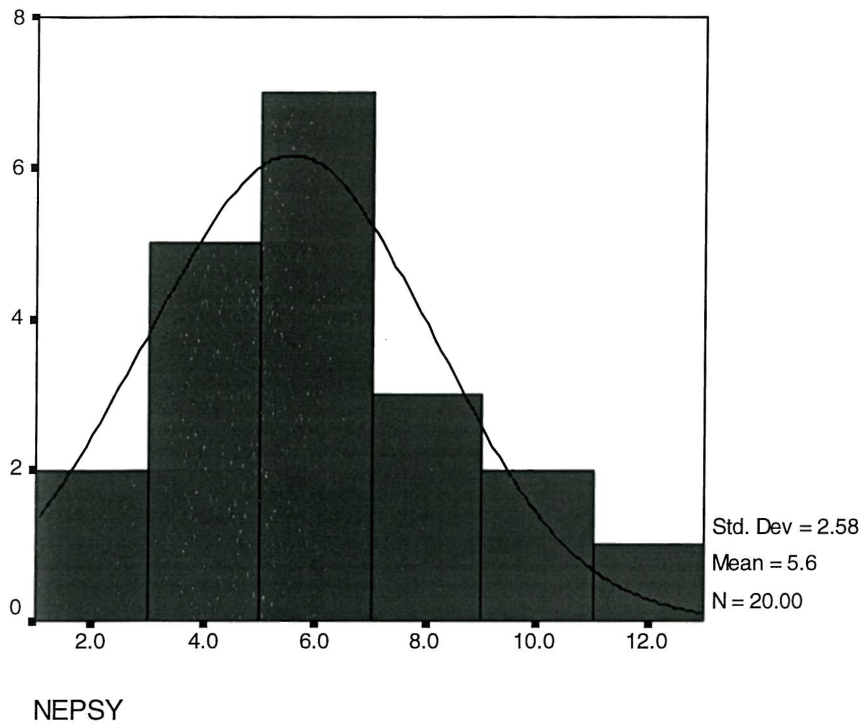
Graph 7: Histogram plot showing distribution of data for adapted modified weigl



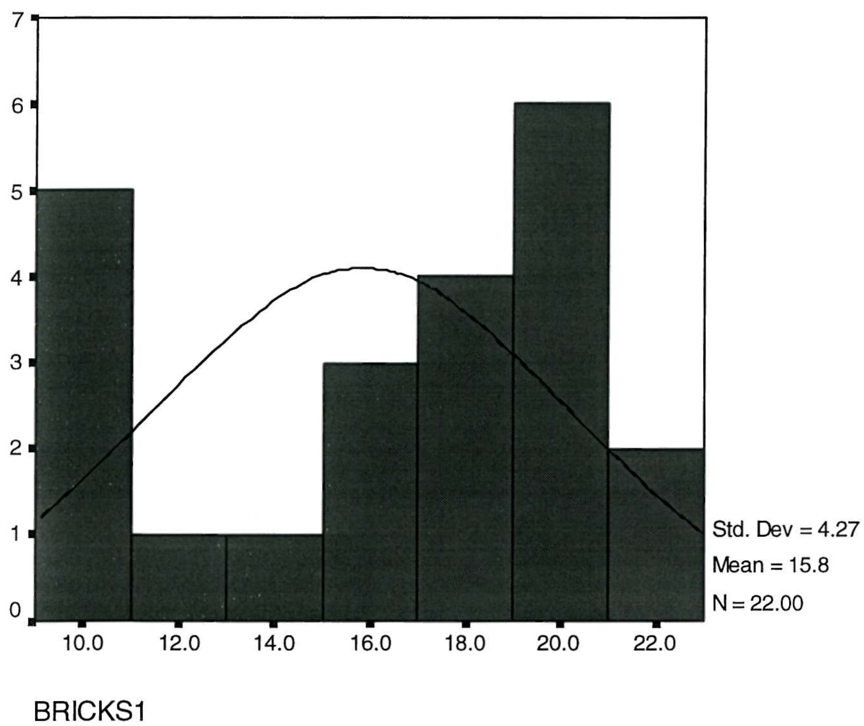
Graph : Histogram plot showing distribution of data for alternating patterns test



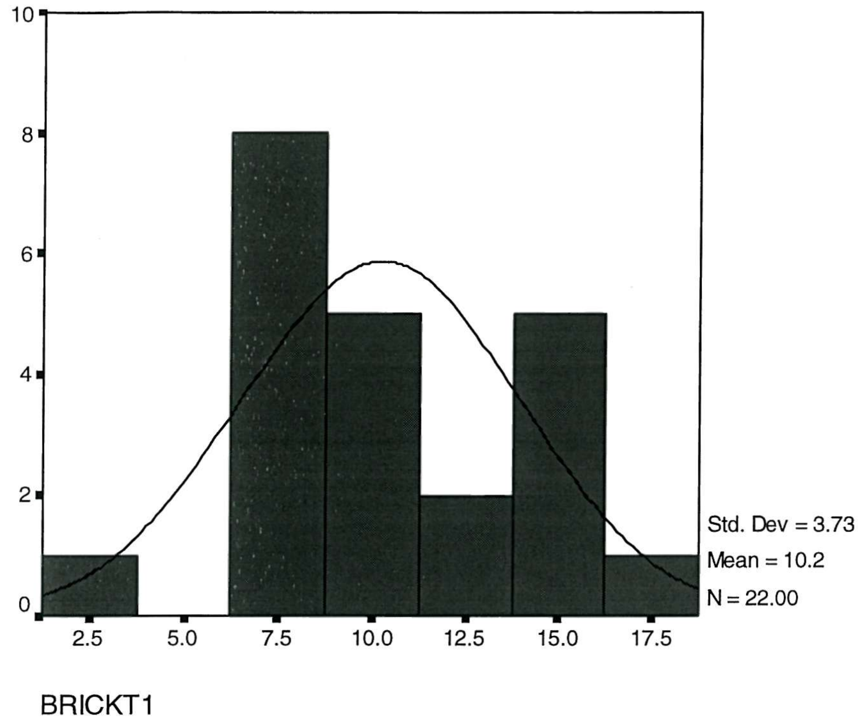
Graph 9: Histogram plot showing distribution of data for NEPSY design fluency



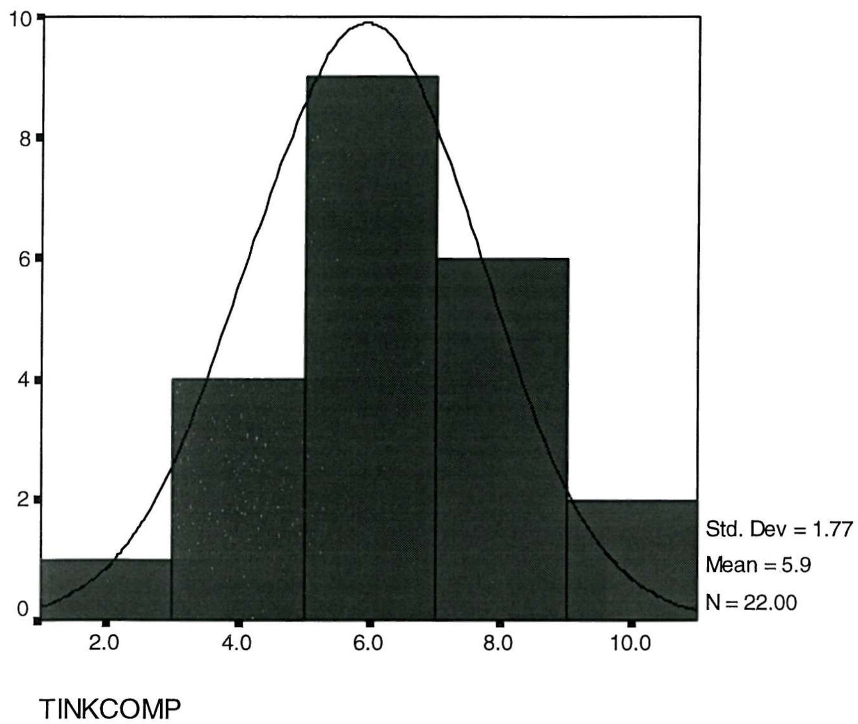
Graph 10: Histogram plot showing distribution of data for brick design fluency sequential changes



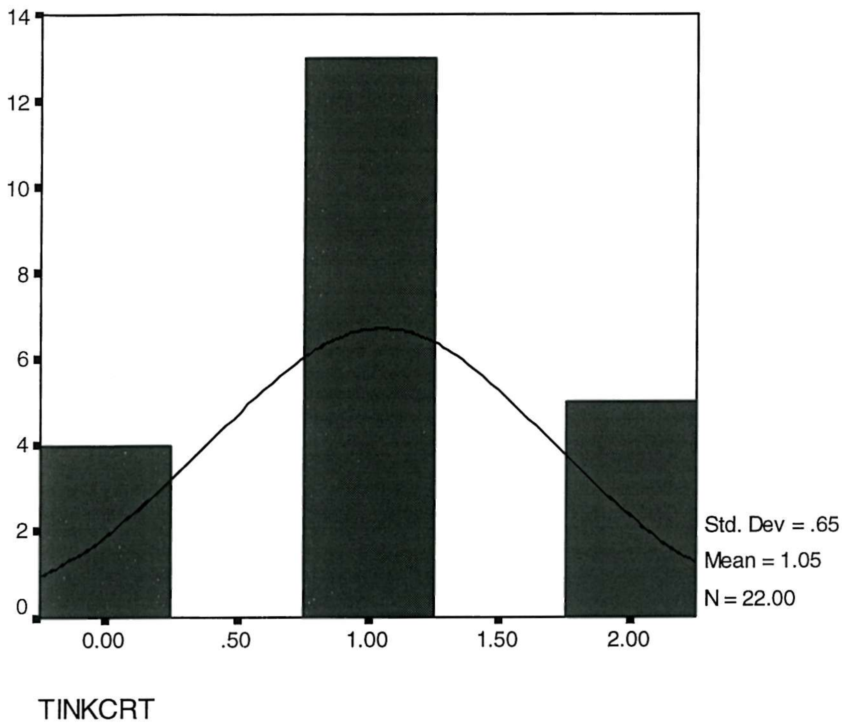
Graph 11: Histogram plot showing distribution of data for brick design fluency total similarities



Graph 12: Histogram plot showing distribution of data for tinkertoy test: complexity score



Graph 13: Histogram plot showing distribution of data for tinkertoy test creativity score



Appendix 10 Skewness data

Skewness

Measure	Skewness	Std. error
BPVS	0.570	0.481
RCPM	0.528	0.481
Box-light test pattern 1	4.796*	0.481
Box-light test pattern 2	1.021*	0.481
Box-light test pattern 3	0.890**	0.481
Adapted Weigl	0.727	0.481
Alternating patterns test	1.766*	0.524
Brick design-fluency sequential changes	-0.600	0.491
Brick design-fluency total differences	0.350	0.491
NEPSY	0.109	0.512
Tinkertoy Test complexity score	0.151	0.491
Tinkertoy Test creativity score	-0.42	0.491

* indicates significantly skewed data (significance is calculated by dividing the skewness statistic by the std. error giving a z-score which if is over 1.96 is significant at the 0.05 level).
**Despite not being skewed, the Brick Design Fluency test pattern 3 is bi-modally distributed.

Appendix 11 Correlations

Nonparametric Correlations

Correlations

			BPVS	RAVENS	BOX1	BOX2
Spearman's rho	BPVS	Correlation Coefficient	1.000	.542**	-.306	-.259
		Sig. (2-tailed)	.	.008	.156	.232
		N	23	23	23	23
	RAVENS	Correlation Coefficient	.542**	1.000	-.258	-.307
		Sig. (2-tailed)	.008	.	.235	.154
		N	23	23	23	23
	BOX1	Correlation Coefficient	-.306	-.258	1.000	.191
		Sig. (2-tailed)	.156	.235	.	.384
		N	23	23	23	23
	BOX2	Correlation Coefficient	-.259	-.307	.191	1.000
		Sig. (2-tailed)	.232	.154	.384	.
		N	23	23	23	23
	BOX3	Correlation Coefficient	-.416*	-.435*	.166	.768**
		Sig. (2-tailed)	.048	.038	.449	.000
		N	23	23	23	23
	WEIGL	Correlation Coefficient	.538**	.047	-.017	-.099
		Sig. (2-tailed)	.008	.832	.940	.654
		N	23	23	23	23
	ALTPAT	Correlation Coefficient	-.351	-.475*	.	.032
		Sig. (2-tailed)	.141	.040	.	.897
		N	19	19	19	19
	BRICK seq	Correlation Coefficient	-.037	-.018	-.329	-.343
		Sig. (2-tailed)	.869	.936	.135	.118
		N	22	22	22	22
	BRICK tot	Correlation Coefficient	.017	-.029	.365	.327
		Sig. (2-tailed)	.940	.899	.095	.138
		N	22	22	22	22
	NEPSY	Correlation Coefficient	.528*	.111	.	.091
		Sig. (2-tailed)	.017	.642	.	.704
		N	20	20	20	20
	TINKCOMP	Correlation Coefficient	.267	.092	-.159	-.138
		Sig. (2-tailed)	.231	.682	.481	.542
		N	22	22	22	22
	TINKCRT	Correlation Coefficient	.142	.218	-.020	-.216
		Sig. (2-tailed)	.527	.331	.931	.334
		N	22	22	22	22

Correlations

			BOX3	WEIGL	ALTPAT	BRICKS1
Spearman's rho	BPVS	Correlation Coefficient	-.416*	.538**	-.351	-.037
		Sig. (2-tailed)	.048	.008	.141	.869
		N	23	23	19	22
	RAVENS	Correlation Coefficient	-.435*	.047	-.475*	-.018
		Sig. (2-tailed)	.038	.832	.040	.936
		N	23	23	19	22
	BOX1	Correlation Coefficient	.166	-.017	.	-.329
		Sig. (2-tailed)	.449	.940	.	.135
		N	23	23	19	22
	BOX2	Correlation Coefficient	.768**	-.099	.032	-.343
		Sig. (2-tailed)	.000	.654	.897	.118
		N	23	23	19	22
	BOX3	Correlation Coefficient	1.000	-.101	-.012	-.152
		Sig. (2-tailed)	.	.647	.961	.501
		N	23	23	19	22
	WEIGL	Correlation Coefficient	-.101	1.000	-.054	.111
		Sig. (2-tailed)	.647	.	.827	.622
		N	23	23	19	22
	ALTPAT	Correlation Coefficient	-.012	-.054	1.000	.366
		Sig. (2-tailed)	.961	.827	.	.124
		N	19	19	19	19
	BRICK seq	Correlation Coefficient	-.152	.111	.366	1.000
		Sig. (2-tailed)	.501	.622	.124	.
		N	22	22	19	22
	BRICK tot	Correlation Coefficient	.207	-.017	-.291	-.845**
		Sig. (2-tailed)	.356	.938	.226	.000
		N	22	22	19	22
	NEPSY	Correlation Coefficient	-.052	.211	-.215	-.234
		Sig. (2-tailed)	.829	.373	.377	.321
		N	20	20	19	20
	TINKCOMP	Correlation Coefficient	.069	.466*	.130	.380
		Sig. (2-tailed)	.761	.029	.597	.081
		N	22	22	19	22
	TINKCRT	Correlation Coefficient	.049	.204	.072	.274
		Sig. (2-tailed)	.830	.362	.768	.217
		N	22	22	19	22

Correlations

			BRICKT1	NEPSY	TINKCOMP	TINKCRT
Spearman's rho	BPVS	Correlation Coefficient	.017	.528*	.267	.142
		Sig. (2-tailed)	.940	.017	.231	.527
		N	22	20	22	22
	RAVENS	Correlation Coefficient	-.029	.111	.092	.218
		Sig. (2-tailed)	.899	.642	.682	.331
		N	22	20	22	22
	BOX1	Correlation Coefficient	.365	.	-.159	-.020
		Sig. (2-tailed)	.095	.	.481	.931
		N	22	20	22	22
	BOX2	Correlation Coefficient	.327	.091	-.138	-.216
		Sig. (2-tailed)	.138	.704	.542	.334
		N	22	20	22	22
	BOX3	Correlation Coefficient	.207	-.052	.069	.049
		Sig. (2-tailed)	.356	.829	.761	.830
		N	22	20	22	22
	WEIGL	Correlation Coefficient	-.017	.211	.466*	.204
		Sig. (2-tailed)	.938	.373	.029	.362
		N	22	20	22	22
	ALTPAT	Correlation Coefficient	-.291	-.215	.130	.072
		Sig. (2-tailed)	.226	.377	.597	.768
		N	19	19	19	19
	BRICK seq	Correlation Coefficient	-.845**	-.234	.380	.274
		Sig. (2-tailed)	.000	.321	.081	.217
		N	22	20	22	22
	BRICK tot	Correlation Coefficient	1.000	.267	-.398	-.182
		Sig. (2-tailed)	.	.255	.067	.418
		N	22	20	22	22
	NEPSY	Correlation Coefficient	.267	1.000	.029	-.091
		Sig. (2-tailed)	.255	.	.902	.704
		N	20	20	20	20
	TINKCOMP	Correlation Coefficient	-.398	.029	1.000	.634**
		Sig. (2-tailed)	.067	.902	.	.002
		N	22	20	22	22
	TINKCRT	Correlation Coefficient	-.182	-.091	.634**	1.000
		Sig. (2-tailed)	.418	.704	.002	.
		N	22	20	22	22

**. Correlation is significant at the .01 level (2-tailed).

*. Correlation is significant at the .05 level (2-tailed).

Appendix 12 Instructions for authors (Journal of Child Psychology and Psychiatry)

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Thompson, A. (1981). *Early experience: The new evidence*. Oxford: Pergamon Press.

Jones, C. C., & Brown, A. (1981). Disorders of perception. In K. Thompson (Ed.), *Problems in early childhood* (pp. 23–84). Oxford: Pergamon Press.

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