

The copyright of this thesis vests in the author. No quotation from it or information derived from it is to be published without full acknowledgement of the source. The thesis is to be used for private study or non-commercial research purposes only.

Published by the University of Cape Town (UCT) in terms of the non-exclusive license granted to UCT by the author.

**Executive Dysfunction and Weak Central Coherence: Neither theory suitably explains a
core cognitive deficit in Autism Spectrum Disorders.**

Michelle Daniels – DNLMIC009

**A dissertation submitted in fulfillment of the requirements for the award of the degree of
Master of Social Science**

Faculty of the Humanities

University of Cape Town

2008

Compulsory Declaration:

**This work has not been previously submitted in whole, or in part, for the award of any
degree. It is my own work. Each significant contribution to, and quotation in, this
dissertation for the work, or works, of other people has been attributed, and has been
cited and referenced.**

Signature:

signature removed

Date: 31/01/2009

ACKNOWLEDGEMENTS

The parents and children who kindly agreed to participate in this research and who gave of their time to do so.

The staff of the schools for supporting this study, allowing testing to take place on the premises, and providing the space to do so.

My supervisor, Dr Kevin G. F. Thomas, for his unwavering patience, encouragement, commitment, and diligence, which made this project possible.

Judy Daniels, for her emotional support, financial backing, and for not giving up on this good investment.

University of Cape Town

TABLE OF CONTENTS

TABLE OF CONTENTS.....	2
ABSTRACT.....	8
INTRODUCTION	9
Autism Spectrum Disorders.....	9
Neurocognition in Autism Spectrum Disorders.....	11
Theories of Executive Dysfunction in ASD	12
Summary of Theories of Executive Dysfunction in ASD	15
Visuo-spatial Ability and Theories of Weak Central Coherence in ASD	16
Summary of Visuo-Spatial Ability and Theories of WCC in ASD.....	20
Allocentric and Egocentric Spatial Ability	21
Summary	23
The Present Research	24
Hypotheses	25
Executive Dysfunction.....	25
Visuo-spatial Ability	25
Allocentric and Egocentric Spatial Ability	26
METHODS	26
Ethics.....	26
Participants.....	26
Design	28
Measures	28
Background.....	28
Wechsler Abbreviated Scale of Intelligence (WASI).....	29
The Grooved Pegboard Test (GPT).....	30
Executive Function	30
Wisconsin Card-Sorting Test-64 Card Version (WCST ⁶⁴).....	30
The Tower of London-Drexel University: 2 nd Edition (ToL).....	31
Visuo-Spatial Ability	31
Block Design (BD)	31
The Children's Embedded Figures Test (CEFT).....	32
The Rey-Osterrieth Complex Figure (ROCF)	32
Allocentric and Egocentric Spatial Ability	33
The Spatial Response Learning Task (SRL).....	33
The Nine Box Maze Test-Child Version (NBMT-CV)	34
Spatial Place Coding Task (SPC)	37
The Computer-Generated (CG) Arena.....	38
Procedure.....	42

Data Analysis	43
Background Measures	44
Demographic Questionnaire	44
Edinburgh Handedness Inventory	44
WASI	44
GPT	45
Executive Function	45
ToL Total Move Score	45
Cognitive Flexibility	45
ToL total correct.	45
ToL total rule violation.	46
WCST ⁶⁴ perseverative errors.	46
Goal Setting	46
ToL total time.	46
WCST ⁶⁴ categories completed	46
RCF-OSS.	46
Attentional Control	47
WCST ⁶⁴ failure to maintain set	47
Visuo-Spatial Ability	47
CEFT Score	47
BD	47
ROCF 36-point Copy	48
Visuo-Spatial Memory	48
ROCF 36-point Recall	48
CG Arena ORT	48
Egocentric Spatial Ability	49
The SRL Task	49
CG Arena Visible Target Trials	49
Allocentric Spatial Ability	50
SPC Task	50
NBMT-CV	50
CG Arena Invisible Trials Number of Times Target Found, and ART Score	51
Targets found.	51
Dwell time	51
ART displacement score.	52
CG Arena Invisible Trials Deviation from Optimal Path Length	52
Spatial Working Memory	53
NBMT-CV Working Location Recall	53
RESULTS	53
Background Measures	53
Executive Dysfunction	57
Overall Executive Function	57
ToL Total Moves	57
Cognitive Flexibility	57
ToL Total Correct	57
ToL Rule Violation	57

WCST ⁶⁴ Perseverative Errors	58
Goal Setting	60
ToL Total Time.....	60
WCST ⁶⁴ Categories Completed	60
RCF-OSS	60
Attentional Control	61
WCST ⁶⁴ Failure to Maintain Set.....	61
The Effect of PIQ on EF Performance.....	61
Summary of Results on Measures of Executive Function	61
Visuo-Spatial Ability.....	63
CEFT Score.....	63
ROCF 36-pt Copy	63
BD Subtest	63
The Effect of PIQ on Visuo-Spatial Ability	64
Summary of Results on Measures of Visuo-Spatial Ability	64
Visuo-Spatial Memory.....	66
ROCF 36-pt Recall	66
ORT.....	66
The Effect of PIQ on Visuo-Spatial Memory	66
Summary of Results on Measures of Visuo-Spatial Memory	66
Egocentric and Allocentric Spatial Abilities.....	69
Egocentric Spatial Abilities	69
SRL Task	69
Summary of results on the SRL	74
CG Arena Visible Trials	75
The Effect of PIQ on Egocentric Spatial Ability	78
Summary of Results of Egocentric Spatial Ability	78
Allocentric Spatial Ability	78
SPC Task.....	78
Summary of Results on the SPC	84
NBMT-CV Object Familiarisation	85
FBMT Total	85
NBMT-CV Total.....	86
NBMT-CV Working Object Recall.....	86
CG Arena Number of Times Target Found, Dwell Time, and ART Score	90
CG Arena Deviation from Optimal Path Length	90
The Effect of PIQ on Measures of Allocentric Spatial Ability.....	91
Summary of Results of Allocentric Spatial Ability	92
Spatial Working Memory	93
NBMT-CV Working Location Recall	93
Summary of Results of Spatial Working Memory	93
DISCUSSION.....	93
Executive Dysfunction	94
Visuo-Spatial Ability.....	101

Allocentric and Egocentric Spatial Ability	105
Methodological Constraints	108
REFERENCES	112
APPENDIX A.....	125
APPENDIX B	126
APPENDIX C	127
APPENDIX D.....	128
APPENDIX E	130
APPENDIX F.....	131
APPENDIX G.....	134
APPENDIX H.....	137
APPENDIX I	139

LIST OF FIGURES

Figure 1. V. Anderson et al.'s (2001) EF framework	14
Figure 2. NBMT-CV apparatus	34
Figure 3. The CG Arena testing room	39
Figure 4. The ORT stimulus card	41
Figure 5. The ART stimulus sheet	42
Figure 6. EF outcome variables grouped according to V. Anderson et al.'s (2001) model	45
Figure 7. Diagrammatic representation of SRL group mean response locations	70
Figure 8. Mean path length across CG Arena visible trials	76
Figure 9. Diagrammatic representation of SPC group mean response locations.....	80
Figure 10. Group deviation from optimal path length across CG Arena invisible trials.....	91

University of Cape Town

LIST OF TABLES

Table 1. CG Arena Demonstration Phase Parameters	39
Table 2. CG Arena Testing Phase Parameters	40
Table 3. Group Differences on Categorical Background Variables	54
Table 4. Group Differences on Continuous Background Variables	56
Table 5. Group Differences on Measures of Executive Function (EF)	59
Table 6. The Effect of PIQ on EF Outcome Variables for the HFA, AS, and TD Groups	61
Table 7. Group Differences on Visuo-Spatial Measures	65
Table 8. The Effect of PIQ on Visuo-Spatial Ability for the HFA, AS, and TD Groups	65
Table 9. Group Differences on Measures of Visuo-Spatial Memory	68
Table 10. The Effect of PIQ on Visuo-Spatial Memory for the HFA, AS, and TD Groups	68
Table 11. SRL Group Mean Response Locations	70
Table 12. SRL Group Mean Response Error	73
Table 13. Scores on CG Arena Outcome Variables	77
Table 14. The Effect of PIQ on Egocentric Spatial Ability for HFA, AS, and TD Groups	78
Table 15. SPC Group Mean Response Location	80
Table 16. SPC Group Mean Error Response	83
Table 17. Group Differences on NBMT-CV Object Familiarisation and FBM Total	87
Table 18. Group Differences on NBMT-CV Outcome Variables	88
Table 19. Group Differences on CG Arena Variables of Allocentric Spatial Ability	89
Table 20. The Effect of PIQ on Allocentric Spatial Ability for HFA, AS, and TD Groups	92

ABSTRACT

Background: Theories of weak central coherence (WCC; a local, detail-specific way of processing information that allows individuals to focus on and remember minutiae) and executive dysfunction (EF dysfunction; an inability to employ goal-directed cognition to plan, organize, and alternate between tasks, or to inhibit incorrect responses) largely dominate current understandings of the neurocognitive profile in autism spectrum disorders (ASD). Recent empirical evidence suggests, however, that neither theory adequately explains the uneven profile of autistic cognition (e.g., attention deficits and relative spatial strengths), and that neither is satisfactorily applicable to autistic individuals across the spectrum. Moreover, recent research provides results contradictory to those predicted by these theoretical frameworks. Consequently, the theories' validity as explanations of a core cognitive deficit in ASD has come into question. **Aims:** The current research attempts to resolve some of the questions raised by the shortcomings of these two theoretical frameworks. In addition, this research aims to investigate the nature of spatial cognition as an assumed strength following from reports of enhanced visuo-spatial skill in ASD. **Methods:** Twenty-five high-functioning autistic (HFA; IQ > 70), 16 low-functioning autistic (LFA; IQ ≤ 70), 13 Asperger's syndrome (AS), 13 mentally retarded (MR), and 22 typically developing (TD) children matched according to sex and handedness were assessed on a comprehensive battery of clinical and experimental neurocognitive measures. There were no group differences on the EF domain, attentional control. On the domains of cognitive flexibility and goal setting, participants in both the AS and LFA groups did not display the EF deficit predicted by the EF dysfunction theory when compared to IQ-matched controls. **Results:** The only support shown for EF dysfunction was with HFA children. These participants made significantly more perseverative errors on the Wisconsin Card Sort Test⁶⁴ (WCST⁶⁴) as an outcome variable of cognitive flexibility and performed more poorly on the Tower of London (ToL) total correct (cognitive flexibility) and total time (goal-setting) scores than controls, without the influence of IQ. In terms of WCC, AS and LFA participants performed no better than IQ-matched controls on visuo-spatial tasks- the Block Design (BD), Rey-Osterrieth Complex Figure Test (ROCF), and Children's Embedded Figures Test (CEFT). Broader spatial cognition was similarly intact but not superior in AS and LFA participants. On those spatial measures not influenced heavily by intelligence, the HFA group were shown to have a diminished capacity for allocentric spatial cognition compared to controls. **Conclusions:** The results of this investigation provided only partial support for the theory of EF dysfunction and no support for the theory of WCC. Instead, they suggest that neither theory is suitable as an explanation of a core cognitive deficit in ASD.

INTRODUCTION

Autism Spectrum Disorders

Autism is an intriguing developmental disorder because it is so diverse in its presentation. The text revision of the fourth edition of Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR; American Psychiatric Association, 2000) lists many *positive symptoms* of autism (i.e., the overt, observable behaviours that reflect the intrinsic underlying deficits). Positive symptoms include unusual facial expressions, impairment or lack of speech, and adherence to rituals. Such explicit behaviours do not necessarily occur in an individual diagnosed with autism, and those that are present arise in different combinations. In addition, atypical patterns of behaviour might vary within the individual as he or she develops. Thus, one can see how wide-ranging the presentation of autism can be (Prior & Ozonoff, 1998; see Appendix A for the DSM-IV-TR criteria for Autistic Disorder).

The diagnostic manual also lists three intrinsic, underlying deficits of the disorder. These deficits are pronounced delays or significant impairments in the development of (1) normal communication, (2) social interaction, and/or (3) imaginative ability. This triad of central features in autism has an onset prior to 3 years of age and is necessary for a diagnosis. Although these major deficits are accepted as the core problems in autism, individuals diagnosed with autistic disorder display a wide array of symptoms that manifest these underlying impairments in greatly differing ways (Bertone, Mottron, Jelenic, & Faubert, 2005). For example, one individual diagnosed with autism might speak but only by constantly mimicking the words of others, and may display a rigid posture and have a limited repertoire of social skills. In contrast, another autistic individual might not speak at all, may be preoccupied with a specific toy or area of interest, and may not wish to engage in any social interaction. Both individuals meet the diagnostic criteria for autism, but they display highly divergent capabilities (Prior & Ozonoff, 1998).

Levels of intellectual functioning also vary considerably within the autistic population. IQ scores in the autistic population can range from below 70, which is a mark of a low level of intellectual functioning with mental retardation, to above 100. Autistic individuals with IQ scores above 70 are commonly termed 'high-functioning' whereas those with IQ scores below 70 are commonly termed 'low-functioning.' A large majority of individuals with autism present with comorbid learning and intellectual disabilities whilst individuals receiving a diagnosis of AS fall predominantly into the average to above-average IQ range. In

an attempt to capture this diversity of behaviours, symptoms, and cognitive functioning, most researchers agree that there is a spectrum of autistic disorders, reflecting the varying levels of severity of maladaptive behaviours, intelligence and language ability (Hill & Frith, 2003; Sigman, Spence, & Ting Wang, 2006).

The broad term 'autism spectrum disorders' (ASD) has been adopted as a way of acknowledging this diversity. The notion of a spectrum of autism disorders therefore comprises classical autism whilst also allowing for the incorporation of every possible presentation of the diverse range of autistic symptoms, and includes individuals with Asperger's Syndrome (AS). AS refers to individuals whose speech is intact but who show signs of social inaptitude. Although DSM-IV-TR (APA, 2000) stipulates that AS must be differentially diagnosed from other specific developmental disorders, including autism, the exact distinction between AS individuals and high-functioning autistic (HFA) individuals is difficult to make (Sigman et al., 2006). The DSM-IV-TR (APA, 2000) diagnostic criteria for AS overlap a great deal with those for AD (see Appendices A and B for these criteria), and leading authors in the field suggest that AS and HFA may differ merely as degrees of severity of a single disorder (Frith, 1999; Kabot, Masi, & Segal, 2003; Meyer & Minshew, 2002). The diagnostic status of AS is therefore controversial, as individuals with AS may share many of the same central features of autism but fail to reach the full diagnostic criteria for autistic disorder (Ozonoff, South, & Miller, 2000).

Furthermore, many recent empirical studies outline the marked cognitive similarities between AS and HFA (see, e.g., Edgin & Pennington, 2005; Manjiviona & Prior, 1999). For instance, Edgin & Pennington's (2005) research revealed no statistically significant differences between AS and HFA children on spatial tasks, EF measures, or tests of perception, suggesting that these disorders share cognitive traits. This and other research suggests that these disorders converge to exist on the same spectrum (Meyer & Minshew, 2002). If an autism spectrum is to be accepted, there should be core symptoms present in every individual with ASD, but there should also be variation in the severity of these symptoms. Similarly, either a unified pattern of cognition should be present in individuals across the ASD spectrum; or a similar pattern of cognitive strengths or deficits, ranging in severity between individuals, should be present across the spectrum (Kabot et al., 2003; Tonn & Obrzut, 2005).

The fact that it is difficult to distinguish between individuals with classic autism and the other variants in the ASD spectrum has consequences for research in the field (Sigman et al., 2006). In some studies, research is conducted with ASD individuals whilst in others only AS participants are recruited (see Edgin & Pennington, 2005; Pertini, 2004; Williams, Minshew, & Goldstein, 2006). Moreover, in research involving only autistic individuals, studies diverge according to whether HFA or LFA individuals participate. Most neuroimaging studies are of the brains of LFA individuals; in contrast, behavioural researchers most often recruit HFA and AS individuals as participants because of their wider range of observable behaviours and greater capacity to respond verbally (Hill & Frith, 2003).

A differing capacity for certain behavioural abilities including speech, and varied prospects for the further acquisition of developmental skills, within ASD parallels a discernible inconsistency in the neurocognitive profile of the disorder itself. For example, attention deficits, inadequate problem-solving, and poor organizational ability are problems widely associated with the disorder. At the same time, visual acuity, enhanced spatial perception, and musical talent are also often observed in ASD (Hill & Frith, 2003). This incongruence in the neurocognitive profile of ASD has propelled a large body of research devoted to defining the underlying constituents of the disorder that impede certain cognitive functions whilst simultaneously facilitating others.

Neurocognition in Autism Spectrum Disorders

Much of the research into autistic disorders explores the veracity of theories of the neurocognitive profile in ASD. Theories of weak central coherence (WCC; Prior & Ozonoff, 1998) and executive dysfunction (EF dysfunction; Frith, 1989) largely dominate current understandings of neurocognitive deficits in ASD (Happé & Frith, 2006). Both theories propose that a 'core deficit' in ASD cognition underlies the behavioural symptoms of the disorders. The key requirements for confirmation of either theory are that it should explain the uneven profile of autistic cognition (e.g., attention deficits and relative spatial strengths), be consistent across measures, and be applicable to autistic individuals across the spectrum (Pennington, 2002). Recent empirical evidence suggests, however, that neither theory meets these requirements (e.g., Edgin & Pennington, 2005).

Theories of Executive Dysfunction in ASD

There is, thus far, no single accepted definition of 'executive function (EF)' in the neuropsychological literature. Although it is a cognitive domain frequently explored in contemporary research, the exact nature of EF, and in particular its constituents, remains unclear. Essentially, however, the term 'EF' refers to an expression of the higher-order cognitive processes that govern the appropriate expression of behaviour. Lezak (1983) initially characterized this construct as the ability to conceive of goals, to plan in accordance with these goals, and to execute ensuing responses effectively. Drawing on this and subsequent descriptions, EF is often expressed in contemporary literature as a broad term for the kind of cognitive functioning that encompasses planning, organization, the inhibition of incorrect responses, set-shifting, abstract reasoning, and working memory (Baddeley, 1986; Hill & Frith, 2003; Jurado & Rosselli, 2007).

Most authors agree on the complexity of EF as well as its importance to human adaptive behaviour. There is, however, much debate over the fundamental organization of EFs. Some authors argue that there is a unifying ability that accounts for all the above-mentioned components of EF. Others propose that the constituents of EF, although related, are distinctly separable facets of cognition. Interestingly, there is empirical evidence to support both viewpoints, which further fuels the controversy around this elusive construct (see Jurado & Rosselli, 2007, for a review). For example, Duncan et al.'s (1996) investigation into EF in patients with frontal lobe damage suggested that the inability to adhere to objectives is associated with general intelligence and working memory. Accordingly, Duncan et al. (1996) concluded that general intelligence and working memory might in fact subsume other executive processes. On the other hand, in a study employing factor analyses, Miyake et al. (2000) determined that set shifting, the updating of immediate memory, and the inhibition of incorrect responses are distinct and separable components of EF. Clearly, in the literature to date there is a great deal of ambiguity regarding the organization of EF and the degree of interrelatedness of the various EFs.

Such ambiguity has obvious consequences for our understanding of ASD: The theory of executive dysfunction is a popular theory of cognition that is often used to describe both social and general cognitive deficits accompanying autism (Baron-Cohen, 2004). This theory as an explanation of the cognitive deficits in ASD is, however, influenced by the ongoing debate over EF in neuropsychology. Indeed, there is empirical evidence in support of an EF

deficit in ASD (see Edgin & Pennington, 2005). Empirical studies show that autistic individuals perform poorly on tasks testing ability to prepare, control and self-monitor impulses by using goal-directed cognition; such studies are the basis of theories of executive dysfunction in ASD (Ozonoff, Pennington, & Rogers, 1991; Prior & Ozonoff, 1998; Russell, 1997). Within the theoretical framework of executive dysfunction, these patterns of cognitive impairment are proposed to account for the insistence on sameness, persistent gesturing, and the unwillingness to enter into social interaction characteristic of individuals with ASD. Nonetheless, the theory's applicability as an explanation of a primary executive deficit in ASD is, in the light of recent empirical evidence, problematic.

Specifically, some researchers suggest that the EF dysfunction theory tends to over-simplify the notion of 'EF' itself (Edgin & Pennington, 2005). As mentioned above, EF is not a clearly definable construct (Jurado & Rosselli, 2007). As such, arguing for an underlying executive deficit in ASD is inherently problematic. The theoretical framework of EF dysfunction in ASD proposes an EF deficit in ASD (Edgin & Pennington, 2005). Yet, if EF is not clearly defined in the literature, this deficit in ASD cannot be accurately identified. If EF is in fact made up of a multitude of separable EF factors, a view that is widely supported, then the theory of EF dysfunction needs to either make clear that every single aspect of EF is deficient in EF or specify which processes are intact and which are deficient (Miyake et al., 2000).

Furthermore, with regard to the actual measurement of EF, standard assessment tools do not necessarily tap into all of the differing EFs (Miyake et al., 2000). A related problem is that studies implicating EF deficits in ASD have used a variety of different measures. Thus, reports of executive dysfunction in ASD diverge according to the type of measures employed in the research (Caron et al., 2004). For instance, many studies suggest impairment on tasks such as the Wisconsin Card Sorting Task (WCST) the Tower of Hanoi, the Tower of London-Drexel Edition, and CANTAB ID/ED- measures of perseverance. On Spatial Reversal, Spatial Span, and A-not-B tasks, that are more attuned to information updating and monitoring, this impairment is, however, less pronounced (see Edgin & Pennington, 2005; Hill & Frith, 2003; and Pennington & Ozonoff, 1996, for reviews). This divergence in executive ability according to task suggests that EF dysfunction in ASD is not as pervasive as the theory of EF dysfunction suggests.

In addition to divergence in executive ability in ASD according to task, much recent research reports inconsistent results on analogous measures of EF. For instance, poor performance is not universal on two tasks that are widely used to support the theory of a core EF deficit in ASD, the CANTAB ID/ED test and the WCST (Edgin & Pennington, 2005; Griffith, Pennington, Wehner, & Rogers, 1999; Minshew, Goldstein, Muenz, & Payton, 1992; Minshew, Goldstein, & Seigel, 1997; Ozonoff, 1995; Pennington et al., 1997; Russell, Jarrold, & Henry, 1999). For instance, Hughes et al. (1994) confirmed an EF deficit in ASD using the CANTAB ID/ED. Yet, using this same measure, also administered by computer, Edgin & Pennington (2005) failed to replicate this EF deficit in a similar ASD population. This incongruence of results across research using identical measures implies that executive dysfunction cannot be a core feature of ASD.

Past research on EF dysfunction in ASD has rarely attempted to define clearly which factors of EF are being measured. Moreover, when more than one measure of EF is used, they are not grouped by executive domain, either in data analysis or data interpretation. This oversight poses methodological challenges for the study of EF in autism (Russo et al., 2007). As EF is such a broad and diverse cognitive construct, standard clinical measures invariably detect divergent aspects of it (Miyake et al., 2000; V. Anderson et al., 2001), and even within tasks, scores of diverse component functions might be derived (e.g. the ToL Total Correct and Total Time Scores; Culbertson & Zillmer, 2006). Consequently, research on EF in ASD may benefit from the adoption of a sound theoretical model of executive domain to clarify the EF pattern in ASD (Manjiviona & Prior, 1999).

V. Anderson et al.'s (2001) model of EF in children and adolescents divides executive processes into a 3-factor framework: (a) attentional control, (b) cognitive flexibility, and (c) goal setting. Various aspects of EF can be captured within this framework (see Figure 1).

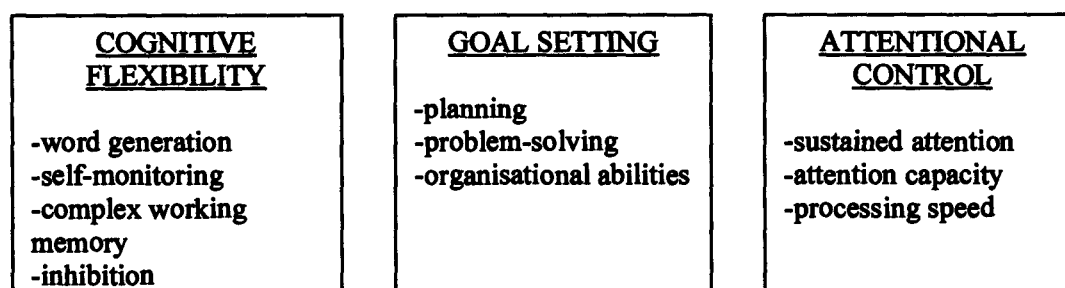


Figure 1. V. Anderson et al.'s (2001) EF framework

Cognitive flexibility includes the ability to shift cognitive set without perseveration. It also incorporates the ability to self-monitor reactions in accordance with task-specific rules and to inhibit incorrect responses. Complex working memory, which includes the maintenance of phonological information (the phonological loop) and visual and spatial information (the visuo-spatial sketchpad), regulated by a central executive (Baddeley, 1986), is included in this domain. The capacity to generate words also falls under this construct. The *goal-setting* domain incorporates planning and organisational abilities, as well as problem-solving skills (i.e., the capacity to conceptualise a problem, formulate a response, to implement the chosen strategy, and to alter responses according to the feedback generated). *Attentional control* encompasses the ability to sustain attention on a task for any extended period of time and the size of attentional capacity. It also includes the speed with which information is processed. This domain-specific model has been shown to be a valid grouping of test measures for the child/adolescent age interval. V. Anderson et al. (2001) report moderate-to-high correlations between EF measures and domains used in this framework. Applying such a model to research on EF dysfunction in ASD may elucidate which specific group(s) of executive processes is intact or deficient in this population.

EF ability in ASD may differ according to EF domain(s). Similarly, differences between groups within the ASD spectrum may determine capacity for intact EF. Whether the theory of EF dysfunction is applicable to individuals across the ASD spectrum is also in need of further empirical investigation. This is because, as mentioned previously, there is noticeable variability in the intellectual ability of individuals across the autism spectrum, and because numerous studies have shown that EF is inextricably associated with general intelligence (Carpenter, Just, & Shell, 1990; Salthouse, Atkinson, & Berish, 2003; Salthouse, Fristoe, McGunthry, & Hambrick, 1998). It is not surprising, therefore, that autistic individuals with comorbid intellectual disabilities are more likely to show EF deficits (Hill & Frith, 2003; Kabot et al., 2003). Individuals with AS are, in contrast, reported to display intact EF (Baron-Cohen, 2004). This suggests that executive dysfunction cannot be a core feature of cognition that applies to all individuals in the ASD spectrum.

Summary of Theories of Executive Dysfunction in ASD

The theoretical framework of executive dysfunction in ASD proposes a core executive cognitive deficit universal to individuals in the autism spectrum (Prior & Ozonoff, 1998).

Whether this theory is a sufficient explanation of the cognitive and behavioural profile of ASD is, however, questionable (Baron-Cohen, 2004; Edgin & Pennington, 2005). Although there is a large body of evidence implicating an executive deficit in ASD, research suggests that it is localized to set shifting or perseverance (Baron-Cohen, 2004). This specificity is, however, largely unstipulated in the theory of EF dysfunction in ASD. Indeed, variance in results according to measures used in research on EF in ASD suggests a need for a more precise definition of EF dysfunction in ASD. Specifically, which aspects of EF in ASD may be deficient and whether certain facets remain intact requires further enquiry. Moreover, recent investigations into EF in ASD provide results that are inconsistent with the theory of EF dysfunction (Edgin and Pennington, 2005; Hill & Frith, 2003; Pennington & Ozonoff, 1996). In fact, some studies fail to replicate an executive deficit in individuals with ASD at all, which brings into question the legitimacy of the theory (Edgin & Pennington, 2005). In addition, the theory of EF dysfunction in ASD falters in its application to all individuals across the autism spectrum (Manjiviona & Prior, 1999; Russell et al., 1999; Wehner & Rogers, 1999). If EF dysfunction is a core cognitive feature of ASD, it should characterize individuals with autism regardless of level of functioning (Pennington, 2002). Recent research, however, indicates that it is unable to do so. Consequently, the theory of EF dysfunction appears an insufficient explanation of a core cognitive deficit in ASD. Accordingly, some authors argue that another dominant theory of the cognitive underpinnings of ASD, the theory of WCC, is better able to predict the behavioural symptoms of the disorder (Happe & Frith, 2006).

Visuo-spatial Ability and Theories of Weak Central Coherence in ASD

Unlike EF, 'central coherence' is an aspect of cognition that is unambiguously defined in the neuropsychological literature. In the processing of visual information, the normal brain displays a strong tendency towards gestalt processing, or a drive for meaning. That is, stimuli are perceived by initial processing of their global, conceptual form rather than by attending to their specific local or perceptual elements. For example, once a word is learned, individuals tend to perceive that word in its entirety and not as a summation of its letters. Similarly, when viewing a picture, witnessing an event or being party to a conversation, individuals drive to perceive and tend mainly to remember the overall meaning conveyed or scene represented, rather than each elemental aspect of it. Frith (1989) described this preference for top-down perception as 'central coherence'; the alternative manner of information processing thought

have enhanced visual-spatial construction and visual memory skills, and, indeed, there is empirical support for enhanced visuo-spatial perception in ASD (see Happe and Frith (2006) for a comprehensive review). Several studies have, however, yielded results that contradict this notion (see, e.g., Brian & Bryson, 1996; Lopez & Leekam, 2003; Ozonoff, Strayer, McMahon, & Filloux, 1994; Plaisted, Swettenham, & Rees, 1999; Ropar & Mitchell, 1999). Catanzaro's (2005) research employing the ROCF as a measure of visuo-spatial construction and memory, for example, failed to find significant differences between HFA and TD children. This suggests that HFA children display intact but not superior visuo-spatial skill, contrary to predictions made by WCC theory.

Moreover, data on visuo-spatial ability in ASD vary according to the measures used. Visuo-spatial strengths put forward as evidence for WCC in ASD are found primarily on tasks such as the Block Design subtest of the Wechsler scales and Embedded Figures tasks (Jolliffe & Baron-Cohen, 1997; Ropar & Mitchell, 2001; Shah & Frith, 1993). On measures of hierarchical categories, visual illusion, and complex figure drawing, findings of superior performance are, however, less consistent (Catanzaro, 2005; Kaland, Mortensen, & Smith, 2007; Mottron et al., 2003; Ozonoff et al., 1994; Ropar & Mitchell, 2001). Moreover, in recent research, there is similar divergence in results between the two tasks on which performance is most commonly cited as superior in ASD participants: the Children's Embedded Figures Test (CEFT) and the Block Design subtest of the Wechsler scales. In Edgin and Pennington's (2005) study, for example, HFA children performed significantly better than TD controls on the CEFT. The ASD sample in that study did not, however, display greater skill than controls on the Block Design test. Such divergence according to task would not be expected if WCC is indeed a primary characteristic of ASD. Consequently, the theory's applicability as a description of a core cognitive feature of the disorder appears problematic. .

Although not replicated in Edgin and Pennington's (2005) research, individuals with ASD have been found, in other studies, to perform significantly better than controls on the Block Design test. Some authors explain this divergence between superior Block Design performance and relative weakness on other measures of visuo-spatial perception (e.g., the ROCF) as being attributable to inherent differences between the two tasks. Specifically, the Block Design subtest, as a three-dimensional constructional exercise, may require a unique set of visuo-spatial skills to perform; some ASD individuals may be able to tap into such

processes in order to complete the designs appropriately. The ROCF, as a two-dimensional, paper figure may draw on a different kind of processing ability, which ASD children may not be able to employ accurately (Edgin & Pennington, 2005). The theory of WCC, in consequence, requires further investigation to re-examine (a) what specific types of visuo-spatial processes may be enhanced in ASD and (b) what measures may tap into these enhanced skills.

A common critique of the WCC theory of ASD is that it purports a local processing bias in ASD owing to a deficit in global processing (Baron-Cohen, 2004). Critics of this theory argue that the inconsistent performance across visuo-spatial tasks may be the result of intact global processing in ASD that is overlooked by the theory of WCC. These authors argue that individuals with ASD may display a bias towards local processing, as it is comparatively superior to global perception. This does not mean, however, that global processing is deficient. If this is the case, and global perception is intact, inconsistent results across different measures of visuo-spatial ability are explicable. Individuals with ASD may be able to utilize global processing on tasks that do not easily facilitate local processing. When assessed on tasks where either processing style is applicable ASD individuals may, however, be inclined to employ a detail-based approach to completing the task (Mottron et al., 2006).

This latter view is supported by recent research. For instance, Rondan and Deruelle (2007) investigated the performance of with adults with autism and AS on tasks involving hierarchical stimuli and geometrical stimuli. Specifically, these researchers employed a hierarchical figures test to investigate whether adults with autism and AS are able to attend to the global aspects of figures. Indeed, they confirmed that individuals with ASD are able to process global aspects of stimuli when they are in priority. Similarly, Caron, Mottron, Berthiaume, and Dawson (2006) reported intact performance by individuals with ASD on tasks requiring global processing (a result that is obviously inconsistent with the theory of WCC). Consequently, WCC may exist in ASD, but it may be accompanied by intact global processing. Acceptance of this view may explain inconsistent data on visuo-spatial ability in ASD across measures. It does not, however, clarify why, within and across studies, levels of visuo-spatial skill are often found to vary between groups within the autism spectrum.

Although WCC theory posits that there is a core cognitive feature identifiable in individuals across the autism spectrum, regardless of age and cognitive ability, empirical research into

the theory predominantly investigates the visuo-spatial profile of children with HFA (e.g. Jarrold & Russell, 1997; Joliffe & Baron-Cohen, 1999; Rinehart et al., 2000; Ropar & Mitchell, 2001) or of those whose IQ is in the mild to moderate range (e.g. Shah & Frith, 1983, 1993). The question of whether predictions from WCC theory hold in LFA individuals is, however, rarely investigated. A recent study considering the visuo-spatial ability of LFA children compared to that of IQ-matched children with severe learning difficulties did, however, provide support for WCC theory in this population. In that study, LFA children were better able to distinguish embedded figures on the CEFT and completed unsegmented block designs more rapidly than matched controls (van Lang, Bouma, Sytema, Kraijer, & Minderaa, 2006). Clearly, these findings require replication.

Interestingly, although the above-mentioned study did show demonstrate the presence of WCC in LFA children, evidence for the theory's applicability to individuals with PDD-NOS remains unsubstantiated. The lack of such evidence, as well as incongruence in the visuo-spatial profile of individuals with AS and those with HFA (e.g., Ropar & Mitchell, 2001), suggests some variability in WCC across the autism spectrum. Such variance should not be present if WCC is indeed a core facet of ASD cognition.

Summary of Visuo-Spatial Ability and Theories of WCC in ASD

In summary, the theoretical framework of WCC in ASD proposes that weak global processing and superior local perception is a core cognitive feature of ASD. As discussed in detail above, however, there is some evidence to contradict this proposition. Moreover, recent empirical evidence suggests that enhanced visuo-spatial skill in ASD is not evident on all measures of visuo-spatial ability used in autism research. In addition, WCC does not appear to be as pervasive across the autism spectrum as the theory purports it should be. If WCC is indeed a processing style that underlies all the manifest symptoms of ASD, then these data are unexpected.

In conclusion, studies show that both the EF dysfunction and WCC theories fail to be replicated across all tasks or groups within the autism spectrum. These data suggest that, although there is some support for each theory in the literature, neither is a sufficient explanation of a core neuropsychological deficit in ASD (Happe & Frith, 2006).

Allocentric and Egocentric Spatial Ability

Visual-spatial ability falls under the broad and multipart faculty of spatial cognition (Caron et al., 2004). The process of spatial cognition requires the computation of questions about where we are, how our bodies and nearby objects are positioned, and what actions should be taken (Marshall & Fink, 2001). In addition, in order to operate on and within the environment, we need to form mental representations of the relationships that exist, both between objects as well as between those objects and ourselves. Thus, an internal model of the world (a 'cognitive map') is created and used to help us manoeuvre our way through space (O'Keefe & Nadel, 1978). This process is spatial navigation, and it illustrates behaviour of the combined workings of spatial learning and memory (Roche, Mangaoang, Commins, & O'Mara, 2005).

As information about the environment is perceived, it needs to be encoded into spatial memory so that it can be formulated into a cognitive map. This encoding can proceed in different ways. An egocentric strategy for spatial coding is a frame of reference that places the self at the centre of an environment. If the space around an individual is encoded in this way, objects are oriented by interpreting how they are related to the self and not to each other. Conversely, allocentric coding represents objects in terms of their relationships to other objects, independent of the self. Both egocentric and allocentric modes of representation help organisms to form a mental image of the layout of the external environment (Roche et al., 2005).

While learning the layout of a space we use one, or both, of the above-mentioned strategies to formulate an image of the environment in the mind. Applying these strategies leads to the acquisition of knowledge about the layout of the environment. The type of knowledge acquired by exercising an egocentric spatial strategy is termed 'route knowledge'. 'Survey knowledge', in contrast, is more closely linked to allocentric coding (Roche et al., 2005). Navigating a highly familiar environment calls on route knowledge, whereas plotting a novel course through known terrain utilizes survey knowledge. In the former scenario, one would move through a space by associating objects, buildings or landmarks in a linear fashion and pursuing a path seemingly unconsciously. This type of navigation is evident when individuals follow a course learnt and remembered by rote. Conversely, survey-based knowledge provides a map-like overview of a familiar space. This broad, topographic mental image of

the terrain allows for the purposive seeking out of new routes to take (McNamara & Shelton, 2003).

With regard to ASD, strengths in broader areas of spatial cognition (including navigation) may be expected based on clinical and anecdotal reports of superior visual-spatial ability in autistic individuals. Recently, however, the nature of spatial cognition in autism has come into question due to a disjunction between those earlier widely reported strengths in visuo-spatial cognition and newer empirical findings to the contrary. For instance, recent studies report that ASD individuals display superior visuo-spatial performance on certain tasks and merely intact performance on others (e.g., Edgin & Pennington, 2005). Edgin & Pennington's (2005) research replicated visuo-spatial strengths on the CEFT and BD. On the Banks and Prinzmetal and Huttenlocher tasks used in Edgin & Pennington's (2005) research, however, the HFA and AS participants performed equivalently to TD controls and showed a similar bias for global forms. These results, suggesting that ASD participants display intact, but not superior, performance on visuo-spatial tasks, have been replicated to varying degrees in recent research (e.g., Catanzaro, 2005; Kaland, Mortensen, & Smith, 2007).

Moreover, studies conducted using spatial navigation tasks have refuted the notion that possible visuo-spatial strengths in ASD extend to skill in broader areas of spatial cognition: Data indicate that performance on measures of spatial navigation does not vary between HFA individuals and TD controls (Caron et al., 2004). Edgin and Pennington (2005) administered a battery of neuropsychological and clinical tests to examine whether spatial navigation in a sample of individuals with HFA and AS was superior or merely equal to TD controls. The researchers discovered that despite proficient local visuo-spatial perception there was in fact no significant difference between the autistic sample and controls on a measure of spatial navigation. Similarly, Caron et al. (2004) discovered, after conducting a series of experiments measuring aspects of route and survey navigation, that adolescents with HFA possessed intact (but not superior) spatial navigation abilities compared to TD children. Together, these findings suggest that spatial cognition is at best intact in the autistic population.

These data are surprising if one assumes that autistic individuals possess remarkable spatial skills (Caron et al., 2004). In terms of proposed abnormalities in the structure and functioning of the hippocampal formation of the right cerebral hemisphere in ASD, however, this outcome is expected (Morris et al., 1999). These abnormalities typically underlie deficits in

allocentric processing (Holdstock et al., 2000). Based on this assumption, Pertini (2004) hypothesized that AS participants would perform significantly worse than TD controls on tasks assessing allocentric spatial ability. Contrary to predictions, however, AS participants performed no differently than TD controls on the study's measures. Consequently, this aspect of spatial navigation is in particular need of further empirical enquiry.

Spatial navigation is an aspect of ASD cognition that has received little attention in the literature to date. As noted before, however, strengths in spatial navigation might be assumed based on the visuo-spatial strengths documented in ASD. The few studies investigating spatial navigation in ASD have found, however, that this faculty is intact but not superior (Caron et al., 2004; Edgin & Pennington, 2005).

Summary

In summary, the visuo-spatial and executive neurocognitive profiles of ASD both appear to diverge between (a) tasks and (b) which ASD individuals (i.e. HFA, AS, or LFA) are recruited in research. This variability cannot be accounted for by either the EF dysfunction theory or the WCC theory; this is a major problem for researchers attempting to relate the neurocognitive profile of ASD individuals to their behavioural symptomatology. Another such problem is that it is often assumed that the visuo-spatial strengths reported in autism extend to broader areas of spatial cognition (e.g., navigation), yet few studies have directly examined the nature of spatial navigation in autism.

Although a relatively new line of investigation, research into the processes of human spatial cognition, specifically spatial navigation, encompasses a rapidly growing body of literature. However, the application of spatial cognitive theory to the understanding of autism is an area of study still in need of greater empirical inquiry. Indeed, the lack of integration of existing findings should be noted. In a recent, state-of-the-art review of autism (Sigman et al., 2006), one that included a neuropsychological perspective, very little attention is given to the possibility of intact spatial cognition in the population or how this might relate to existing theories widely used to explain cognitive deficits in ASD. Moreover, the review mentions that between 50 and 70% of children with autism are low functioning. Yet, in the meagre literature on spatial navigation in autism, the samples consist of HFA or AS individuals (Caron et al., 2004; Edgin & Pennington, 2005).

The Present Research

This research attempts to resolve some of the queries raised by the shortcomings of the EF dysfunction and WCC theoretical frameworks. Specifically, this study aims to investigate whether either theory is suitable as an explanation of a core cognitive deficit in ASD. As such, this study attempts to determine the extent to which executive deficits in ASD are consistent across measures. Similarly, this research explores whether visuo-spatial superiority in ASD (as predicted by the WCC theory) extends across various tests of visual-spatial cognitive ability. If EF weaknesses or visuo-spatial strengths are not replicable across tasks, this study endeavours to isolate which specific aspects of EF and visuo-spatial cognition are deficient, intact, or superior in ASD. To achieve these aims, this research incorporates measures that have previously been widely used to provide evidence for WCC and executive dysfunction in ASD. These measures are of specific interest as they have also, in recent studies, yielded results that contradict these theories.

In addition, this study breaks EF down into constituent domains according to V. Anderson et al.'s (2001) model. Most previous studies use more than one common measure of EF (see Edgin & Pennington, 2005, for a review). Yet, these tests in fact measure correlated but separable aspects of EF (Miyake et al., 2000). Most researchers use these measures to investigate whether the theory of EF is applicable as an explanation of a core cognitive deficit in ASD and results have been highly contradictory (Edgin & Pennington, 2005). This may mean that the theory is only valid according to certain tasks and therefore some but not all EF factors. This study uses a sound model of EF, under which to group measures, to investigate this prospect.

The present study also aims to address the need for continuing investigations into spatial navigation in ASD as a more specific aspect of visuo-spatial ability. The current research utilizes a broad range of measures to assess the nature of spatial navigational ability in an ASD sample. This cognitive domain is of particular interest in light of the above-mentioned variance in results of prominent investigations in the field. Drawing on Edgin and Pennington's (2005) research, a comprehensive battery of experimental tasks is employed to determine the overall level of general spatial ability in ASD. Moreover, the present study makes use of measures employed by Pertini (2004) that specifically tap into allocentric and egocentric spatial coding strategies.

An important feature of the present study is the inclusion of HFA, LFA, and AS participants. Consequently, the results of this study are evaluated in terms of how they represent the profile of cognitive strengths and weaknesses across the ASD spectrum. Much recent research on ASD investigates the relationship between HFA and AS due to the marked similarities of many of their behavioural symptoms. Most of these studies determined that there is a great deal of overlap in the neurocognitive profiles of these disorders (see Caron et al., 2004; Edgin & Pennington, 2005; Ozonoff, South, & Miller, 2000). The present study compares the results of a comprehensive battery of EF and spatial cognitive tasks of individuals with AS, HFA, and LFA. This notion is in line with the above-mentioned research that explores the similarities and differences in cognitive profile between individuals with AS and those with HFA (Ozonoff et al., 2000). As the literature commonly employs only HFA or AS participants (Edgin & Pennington, 2005; Jarrold & Russell, 1997; Jolliffe & Baron-Cohen, 1999; Manjiviona & Prior, 1999; Rinehart et al., 2000; Ropar & Mitchell, 2001; Williams et al., 2006), there is a dire need to investigate the validity of the EF dysfunction and WCC theoretical frameworks in other ASD populations. If, indeed, these theories are universal to ASD, underlying patterns of cognition should be similar in all ASD participants (Pennington, 2002). If not, specific differences between ASD sub-groups will be identified.

Hypotheses

Executive Dysfunction

The theory of EF dysfunction in ASD suggests that there is an executive deficit universal to ASD (Ozonoff et al., 1991; Russell, 1997). As such, it is hypothesised that if this theoretical framework is a sufficient explanation of a core deficit in ASD, HFA, LFA, and AS groups will perform significantly more poorly than controls on the measures of EF employed in the current research.

Visuo-spatial Ability

According to the theory of WCC in ASD, individuals across the autism spectrum exhibit a bias towards local visual processing. As such, the theory posits that individuals with ASD will perform consistently better than matched controls without ASD on tasks of visuo-spatial perception (Frith, 1989; Happe, 1999; Happe & Frith, 2006). In the current research it is therefore hypothesised that if the theory of WCC is a sufficient explanation of a core

cognitive deficit in ASD, HFA, LFA, and AS participants will outperform controls on all the measures of visuo-spatial ability employed in this research.

Allocentric and Egocentric Spatial Ability

Past research suggests that allocentric spatial place coding is deficient in ASD (Morris et al., 1999). It is therefore hypothesised that HFA, LFA, and AS participants will perform more poorly than controls on the measures of allocentric spatial place coding employed in this research. Conversely, egocentric spatial place coding is reportedly superior, or at least intact, in ASD (Pertini, 2004). Consequently, it is hypothesised that HFA, LFA, and AS participants will perform at least as well as controls on the measures of egocentric spatial place coding employed in this research. In terms of broader spatial cognition, superior spatial navigation in ASD is assumed based on reported strengths in visuo-spatial processing. If this is indeed the case, one would expect the HFA, LFA, and AS groups to outperform controls on the navigation tasks employed in this research.

METHODS

Ethics

This study followed the ethical guidelines for research with human subjects outlined by the Health Professionals Council of South Africa (HPCSA) as well as the University of Cape Town's (UCT) Codes for Research. Ethical approval for the entire study was obtained from the Research Ethics Committee of the UCT Department of Psychology. In addition, permission to conduct this research in the relevant government schools was granted by the Western Cape Education Department (see Appendix C) and the Gauteng Education Department (see Appendix D), as well as each school's respective governing body. In the case of independent/private schools, the school's governing body granted permission to conduct the study.

Participants

Eighty-nine participants between 6 and 16 years of age ($M = 10.45$, $SD = 2.62$) participated in this research. They were recruited from three schools in the Western Cape, eight schools in Gauteng, and one school in KwaZulu-Natal. The major inclusion criteria were that participants (a) spoke (or understood, if speech was absent) English, (b) were taught either in English or in both English and Afrikaans, and (c) had no uncorrected visual impairment or

other medical problem that may have affected their ability to complete the experimental tasks. Information regarding those criteria was obtained from teachers and/or parents.

Each participant was part of either the high-functioning autism group (HFA; $n = 25$), the low-functioning autism group (LFA; $n = 16$), the Asperger's syndrome group (AS; $n = 13$), the mental retardation group (MR; $n = 13$), or the typically developing group (TD; $n = 22$). Across groups, participants were closely matched in terms of sex and handedness, and as far as possible by chronological age and Performance IQ (PIQ). Details for each of the groups follow.

Forty-one children previously diagnosed with AD were recruited from schools that specialise in the education of children with autism. A condition of admission to these schools was a diagnosis of AD. Thus, diagnostic information on each AD participant was gathered independently of this study. In three of the schools from which AD participants were recruited, the Childhood Autism Rating Scale (CARS; Schopler, Reichler, & Renner, 1992) was administered by either a qualified clinical psychologist or an educational psychologist prior to admission. The other school from which these participants were recruited required applicants to produce proof of a diagnosis of AD by a qualified paediatrician prior to admission. AD participants were assigned to either the HFA ($PIQ > 70$) or LFA ($PIQ \leq 70$) groups only after administration of the Wechsler Abbreviated Scale of Intelligence (WASI; Psychological Corporation, 1999) in the context of this study.

Thirteen children previously diagnosed with AS were recruited from remedial schools dedicated to educating children with mild learning difficulties. These participants had been diagnosed with AS by a multi-disciplinary team including a speech therapist, occupational therapist, and educational psychologist using clinical observations and parent/teacher reports.

Thirteen children were recruited from a special needs school specialising in the education of children with moderate to severe mental retardation. These participants had all been previously diagnosed with moderate to severe mental retardation as a condition of enrolment in the school. None of these participants presented with comorbid AD or AS. This diagnostic information was produced independently of this study and was gathered from the school's principal and participants' school records. This MR group was included as a non-ASD PIQ-

based control group for the LFA group. As such, all participants in this group were required to have a PIQ in the range of 55-70.

Twenty-two TD children were recruited either from an existing research participant pool drawn on by colleagues at UCT or from an independent participant pool sourced by the researcher. These TD participants had no prior clinical diagnoses; this information was provided by each participant's school and/or parent(s). All of these participants were pupils at mainstream independent or government schools. This TD group was included as a non-ASD control group for the HFA and AS groups. As such, all participants in this group were required to have a PIQ of > 70 .

Design

This study is a quasi-experimental, cross-sectional between-group comparison. As noted above, participants were organized into five groups of children: 1) those with a clinical diagnosis of AD and $PIQ > 70$ (i.e., an HFA group); 2) those with a clinical diagnosis of AD and $PIQ \leq 70$ (i.e., an LFA group); 3) those with a clinical diagnosis of AS; 4) those with moderate-to-severe mental retardation but no clinical diagnosis of AD and $PIQ \leq 70$ (i.e., an MR group); and 5) those with no learning disability or clinical diagnoses and a $PIQ > 70$ (i.e., a TD group). Groups were compared on measures of EF, visuo-spatial ability (as a measure of WCC), egocentric spatial ability, and allocentric spatial ability.

By convention, an effect size of 0.40 represents a large effect size for F tests such as one-way ANOVA (Cohen, 1977, 1988). Under these circumstances, sufficient power to correctly reject the null hypothesis is 0.80. Given these conventions, at $\alpha = 0.05$, across five groups, an a priori power analysis using the G*Power software version 3.0.3 (Buchner, Erdfelder, & Faul, 1997) indicated that a total sample size of 80 was sufficient to obtain adequate power. Consequently, this study's power to detect differences between groups, with a total sample of 89 participants, was greater than 0.80 (Erdfelder, et al. 1997).

Measures

Background

Demographic Questionnaire

A simple questionnaire (see Appendix E), devised by the researcher and completed by parents and/or teachers, was used to obtain information about the participant's age, sex,

ethnicity, schooling details, and computer experience. The amount of time spent using a computer was included as research suggests that this factor may facilitate spatial performance (Subrahmanyam & Greenfield, 1994).

Edinburgh Handedness Inventory

The Edinburgh Handedness Inventory (Oldfield, 1971) measures hand preference. Each participant's teacher indicated which hand the child would be most likely use 'always', 'sometimes', or 'never' to complete 10 hand-related activities. The activities described are common household or sport-related actions that require the use of one hand to complete (e.g., brushing ones teeth, or writing). This measure was included as research suggests that handedness is related to differences in aspects of spatial processing (e.g., global and local figural perception; Bradshaw, 1989).

Wechsler Abbreviated Scale of Intelligence (WASI)

The WASI (Psychological Corporation, 1999) was employed to assess the participants' levels of general intellectual functioning. The WASI is a brief, individually administered test, intended for use with individuals from 6 to 89 years of age. It is a widely used and robust measure that has been successfully administered to clinical populations (see, e.g., Stano, 2004). The WASI consists of four subtests: Vocabulary, Similarities, Block Design, and Matrix Reasoning. The combined age-adjusted scaled scores of the Vocabulary and Similarities subtests provide a measure of Verbal IQ (VIQ). Similarly, the combined age-adjusted scaled scores of the Block Design and Matrix Reasoning subtests provide a measure of Performance IQ (PIQ).

Typically, all four subtests are administered to determine a Full Scale IQ score (FSIQ). In this study, however, only the Performance subtests were administered. As mentioned above, one of the core deficits across the autism spectrum is poor language ability (APA, 2000).

Consequently, the WASI Verbal subtests were not included in this study as they may have artificially lowered the ASD participants' FSIQ scores. This deviation from standard practice still, however, allowed for an estimate of general intellectual ability. The Block Design subtest is particularly robust in this regard. It is a good predictor of general intellectual functioning as it has a high correlation ($r = .74 - .80$) with FSIQ (Sattler, 1992).

The WASI Performance subtests were administered and scored according to the procedure outlined in the battery's accompanying manual (Psychological Corporation, 1999).

The Grooved Pegboard Test (GPT)

The GPT (Ruff & Parker, 1993) was included as a measure of hand-eye coordination and fine motor ability. This information indicated whether the participants could attain the appropriate levels of motor performance to complete the rest of the test battery.

Executive Function

Wisconsin Card-Sorting Test-64 Card Version (WCST⁶⁴)

The WCST⁶⁴ (Kongs, Thompson, Iverson, & Heaton, 2000) is a measure of EF (more specifically, set shifting and the inhibition of impulsive responding). Effective completion of the WCST⁶⁴ also requires concentration, planning, organisation, working memory, and concept formation. The WCST⁶⁴ is often used in clinical and neuropsychological research and practice. It is a robust measure with good test-retest reliability ($r = .90$) and sound construct validity that is successfully administered to individuals from 6½ to 89 years of age (Kongs et al., 2000). The WCST⁶⁴ is employed frequently in studies of executive dysfunction in ASD. Most, although interestingly not all, such research reports significantly poor performance by ASD participants compared to controls on this measure (see Edgin & Pennington, 2005, for a review). For these reasons, the WCST⁶⁴ was utilized in the current research.

The WCST⁶⁴ consists of 4 stimulus cards and 64 response cards. The stimulus cards are: one red triangle, two green stars, three yellow crosses, and four blue circles. The response cards depict varying forms (crosses, circles, triangles, or stars), colours (red, blue, green, yellow), and numbers of forms (one, two, three, four). Utilizing feedback received from the researcher as to whether their responses are correct or incorrect, each participant must organize the response cards into the categories form, number, or colour as determined by the stimulus cards. After every 10 correct responses the appropriate sorting principle changes. For example, at the onset of the test the appropriate sorting principle is to colour. If the participant places a response card with one green triangle into the category under the stimulus card depicting two green stars, the response is correct. After 10 responses similarly determined by the colour of the stimuli on the response card, the sorting principle changes to form. At this stage, following feedback from the researcher that the response is incorrect, the participant needs to determine how to alter the sorting strategy to receive positive feedback from the researcher (Kongs et al., 2000). The WCST⁶⁴ was scored according to procedures outlined in the accompanying WCST⁶⁴ test manual.

The Tower of London-Drexel University: 2nd Edition (ToL)

The ToL (Culbertson & Zillmer, 2006) was also used to assess EF. The ToL is designed to assess executive planning ability. This includes the ability to conceptualize change, generate alternative responses, and sustain attention. Essentially, adequate performance on this task requires the formulation or planning of a response before taking action. The ToL consists of two wooden boards, one used by the researcher and one used by the participant, each with 3 pegs of decreasing length and 3 coloured (red, blue, and green) beads. The objective of the test is for the participant to copy the design or pattern of beads that the researcher presents on his/her board in as few moves as possible. The participant must make sure that (a) each bead is always placed back onto a peg, (b) he/she does not pick up more than one bead at a time, and (c) he/she does not overload the two shorter pegs with too many beads. The design of the ToL apparatus compels the participant to consider each problem and plan an appropriate response prior to moving any of the beads. If the participant does not do this, he/she invariably encounters a setback in solving each problem (Culbertson & Zillmer, 2006). In research on EF in ASD, participants are often assessed on either the ToL or variants of the task such as the Tower of Hanoi. Frequently, ASD participants are reported to perform poorly on these tests (see Edgin & Pennington, 2005, for a review).

Visuo-Spatial Ability

Block Design (BD)

The BD subtest of the WASI was of interest as a measure of visuo-spatial ability. This subtest specifically relies on techniques of visual processing and spatial construction. In many studies, individuals with autism are reported to perform significantly better than TD controls on this task (Caron et al., 2004). Recently, however, this notion has been contested in the literature, as contradictory findings have emerged (Edgin & Pennington, 2005).

One frequently used deviation from standard practice was employed in the administration of the BD subtest to certain participants in this study. Some of the participants insisted on total accuracy and continually attempted to match the sides of the blocks as well as the tops in this task. They therefore benefited from the placement of the model inside a box. This way, they were unable to focus on the irrelevant sides of the blocks used in this task (Prifitera, Weiss, & Saklofske, 1998).

The Children's Embedded Figures Test (CEFT)

The CEFT (Witkin, Oldman, & Karp, 1971) is widely used in paediatric neuropsychological research as a measure of 'disembedding', i.e. the ability to break up an organised visual field into its constituent elements. The CEFT comprises a series of images familiar to children (for example, a picture of a doll or of a clock) each containing either a 'triangle' or a 'house' shape. Initially, the participant is oriented to these shapes and receives practice on how to differentiate the exact shape from an array of similar forms. Subsequently, the participant attempts to locate the shape hidden in each picture. In total, each participant views 25 pictures of increasing complexity. The CEFT has good internal consistency ($r = .83$ to $.90$) and external validity ($r = .70$ to $.86$) estimates.

In the present research, the CEFT was administered and scored according to the procedures outlined in its accompanying manual. One variation from this practice was, however, the age group assessed using this instrument. Although the CEFT is recommended for use with children between the ages of 7 and 12, in the current study, children from 6 up to the age of 16 were testing with measure (Witkin et al., 1971). As the CEFT was employed exclusively to make comparative inferences in this research, this deviation from usual procedure should have no bearing on its validity. The CEFT is often used in ASD research on WCC, as effective performance on this task requires one to overlook the global form of an image in order to attend to its figural components. Although recent research provides evidence to the contrary, WCC theory predicts that individuals with ASD should perform significantly better than controls on this measure (Edgin & Pennington, 2005).

The Rey-Osterrieth Complex Figure (ROCF)

The ROCF (Osterrieth, 1944; Rey, 1941) is a commonly used measure of visuo-spatial ability, visual memory, global-local visual processing, and EF. Successful completion of the task requires visual and spatial planning, construction, memory, and organisation. The ROCF is commonly used in neuropsychological research and clinical screening, and is frequently used in studies of spatial cognition in children with autism (see Happe & Frith, 2006, for a review).

The ROCF is an intricate, two-dimensional image composed of a central rectangle equally divided into eight parts. A triangle borders the right side of this rectangle. Within, and adjoining, both these shapes are various other forms, lines, and details. In the ROCF test, the

figure is presented to the participant on a laminated card, on which it was horizontally positioned. In this study, each participant used a blank sheet of paper and coloured pencils to redraw the figure. Initially, each participant attempted to copy the ROCF directly from the stimulus card. Approximately every 45 seconds, the participant was given a different coloured pencil until he/she indicated that he/she was finished. For all participants, the order in which the pencils were given was the same. Once the participant had finished drawing, the card was removed. The participant was not told to try to remember the figure. After a 5-minute filled delay, each participant attempted to redraw the figure from memory using the same coloured pencils, given to him/her in the same order at 45-second intervals.

Allocentric and Egocentric Spatial Ability

The Spatial Response Learning Task (SRL)

The SRL (Pertini, 2004) assesses the ability to employ egocentric response learning. In the SRL task, a large sheet of cardboard (80cm x 40cm) was placed in front of the participant who was seated on a chair, in front of a desk. The researcher was seated directly opposite the participant at the desk. The participant was given a small, thin figurine and asked to hold it by his/her side, and close his/her eyes. While the participant's eyes were closed, the researcher guided his/her hand over the cardboard that was positioned directly in front of them. The location in which the researcher placed the participant's hand was where he/she should have later attempted to replace the object. The researcher instructed the participant to hold his/her hand over the cardboard for three seconds then return it to his/her side. Following another 3 seconds, the participant opened his/her eyes and position the object on the cardboard in the same location above which his/her hand was held by the researcher. Eight trials of this procedure were administered. The nature of this procedure advocated the use of egocentric spatial learning as no environmental cues could be used to aid in the encoding of the locations of the objects. The researcher had a detachable ruler on her side of the desk that could not be seen by the participant from where he/she was seated opposite. Each of the eight true object locations was marked on the researcher's ruler so she knew where to place the object. When the participant replaced the figurine, the researcher recorded the position in millimetres from the right side of the cardboard at which the object was replaced, using the ruler as a guide (Pertini, 2004).

This measure was included as a test of egocentric spatial ability. Children with ASD are expected to have an intact capacity for this type of spatial processing. In other words, these participants should perform equally to non-ASD controls on this measure (Pertini, 2004).

The Nine Box Maze Test-Child Version (NBMT-CV)

The NBMT-CV (Pentland, Anderson, & Dye, 2003) is an experimental measure that taps into non-verbal memory and distinct aspects of spatial processing and orientation. More specifically, it allows researchers to discern whether the child is learning where objects are by relating them to other objects rather than to the self (i.e., utilizing an allocentric frame of reference). In addition, it assesses memory for objects, locations, and the associations between them, which requires the ability to accurately encode and recall spatial information allocentrically (Pertini, 2004). A pilot study of the NBMT-CV found that it correlated well with standard measures of spatial memory (Pentland et al., 2003).

Administration of the NBMT-CV occurred in three stages. The first stage completed was *Object Familiarisation*, the second was a practice test (the *Five Box Maze*), and the third was the full *Nine Box Maze test* (see Figure 2 for an image of the apparatus used). The score sheets used in each stage are presented in Appendix F.

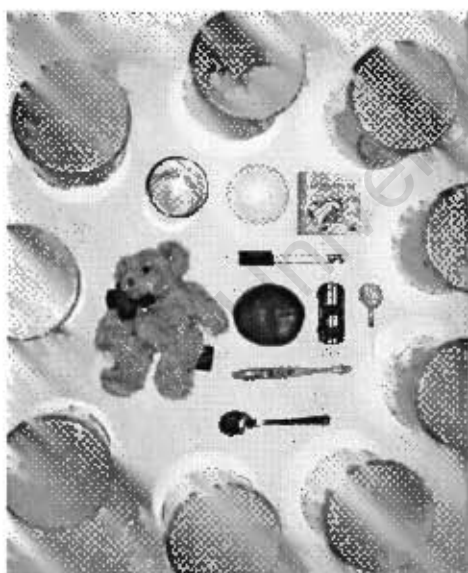


Figure 2. NBMT-CV apparatus

During the Object Familiarisation stage, the participant was seated at a small table and shown a set of 10 common household objects and toys (a plastic spoon, a teddy bear, a toy car, a toothbrush, a felt marker, an apple, a cup, a tennis ball, a small book, and a lollipop). These items were presented to each child in a fixed order. The examiner asked each participant to try to remember the objects. In order to engage the child with the materials and to establish that they understood what each object was, the examiner asked the child “What is it?” and “Would you play with it?” Then followed a 1-minute filled delay during which the objects were not visible to participants. After the delay, the participant attempted to recall as many objects as he/she could (Pertini, 2004). If the children in the AD group were non-verbal and unable to tell the examiner what objects had been presented, they were asked to choose the objects from a card depicting pictures of the items that had been shown as well as some that had not.

The Five Box Maze Test (FBMT) stage followed immediately after the Object Familiarization stage. Five identical bins were arranged on the table in a symmetrical circle. The bins were in predetermined and recorded locations and spaced at equal distances from each other. The participant began this task seated in the position he/she occupied at the beginning of the procedure. The examiner removed two objects from a box in which they were kept out of view of the participant and indicated that she was going to place the items into two separate bins and secure the lids. This action was performed in full view of the participant. Great care was taken to ensure that the lids were firmly secured onto the containers so as not to provide inadvertent cueing as to where the objects had been hidden. The examiner then asked the participant to move to another designated position around the table.

Once re-seated, the child was asked to identify which objects were hidden. If the child answered correctly, the researcher confirmed that the child was correct and awarded him/her one point. The participants who were able to recall freely the objects were awarded an additional point for object recognition as well. If the child was unable to recall the items correctly, the researcher showed the child a picture booklet that contained a picture of the objects in use in a spatial array. The child was asked to select the pictures that corresponded to the hidden objects. Positive feedback and a point were awarded if the child was able to recognize the items. If the child was unable to recognize the objects, he/she was told which ones were hidden and no points were recorded.

Subsequently, the researcher asked the child to point to the bins in which there were hidden items. One point was given for each bin correctly identified. Similarly, a point was awarded for each correct response as the child then attempted to indicate to the researcher which items were hidden in which bins. If the participant hesitated or gave multiple responses, the researcher asked the child which response was intended to be the first. After the participant responded, the researcher removed the lids from the two bins to reveal the objects inside.

The participants who were able to identify which objects were in the correct bins (i.e. a full score of eight points) on the first FBMT trial, proceeded immediately to complete the Nine Box Maze test. These participants were awarded full points (24) for the FBMT. Those who were unable to do so attempted two more trials of the FBMT. If a participant was able to obtain a score of eight on the second trial, he/she proceeded to the Nine Box Maze and was awarded full marks for the remaining FBMT trial. If a participant did not obtain a maximum score of eight points on any of FBMT trials, he/she was not allowed to proceed to the Nine Box Maze stage.

The Nine Box Maze test followed the same procedure as the Five Box Maze test. However, in this case, 9 bins and all 10 objects were used, and four trials were completed (Pentland et al., 2003; Pertini, 2004).

Individuals with ASD have, in previous studies, displayed deficits in allocentric spatial coding and memory (Pertini, 2004). Consequently, it is predicted that HFA, LFA, and AS participants in this study will perform more poorly on this task than will TD and MR participants.

In addition, the NBMT-CV (Pentland et al., 2003) includes an assessment of working memory. Throughout administration of the test, two of the four objects hidden in the bins remain the same across trials. As the scoring sheet in Appendix F indicates, in the present administration of the task, the cup and the car were hidden away from the participants in each trial. The remaining two objects were chosen in a random order that was fixed for all participants as a measure of working memory. Similarly, spatial working memory is measured by the participants' ability to remember the two locations in which an object was

not placed in every trial (i.e., all bins used except bins 3 and 8, which remained constant across trials).

Spatial Place Coding Task (SPC)

The SPC, like NBMT-CV, measures the ability to process and remember spatial locations. Moreover, it assesses whether a fine-grained allocentric place coding strategy is employed to do so.

In the SPC task, a large sheet of cardboard (80cm x 40cm) was placed in front of the participant who was seated on a chair at a desk. The experimenter placed a small, thin figurine onto the cardboard in front of the participant. The participants were asked to carefully examine the object for up to 5 seconds as it was positioned on the cardboard, and to attempt to remember its location. Following this coding stage, the participant was asked turn around slowly, during which time the cardboard was moved 20 centimetres to the left or right of its original location at the centre of the desk. The cardboard was moved to the left or the right of its original location in an order fixed for all participants. Once facing back towards the cardboard, the participant attempted to replace the object on the cardboard in the same place it occupied previously. Each time the object was repositioned it was placed in one of eight locations, which were at equal intervals from each other along the midline of the cardboard. The cardboard was moved either 20cm to the left or right of its original location. Performance on the SPC task was scored as the mean distance (in mm), on the horizontal line, between the location the participant placed the object and the right edge of the cardboard. Twenty-four such trials were completed (Pertini, 2004).

By altering the position of the cardboard, the premise of the SPC task is that the participant is forced to code the position of the figurine by way of allocentric processing. The participant's viewpoint of the object changes continuously during this task. As such, an egocentric positioning of the object leads to less accurate remembering of the figurine's location.

Previous research predicts that children with ASD are deficient in allocentric spatial processing. In Pertini's (2004) study, however, this was not the case for AS participants. Consequently, only the HFA and LFA participants in this research might exhibit poor allocentric spatial ability on this task when compared to non-ASD controls.

The Computer-Generated (CG) Arena

The CG Arena is a measure of overall spatial place learning and navigational ability (Thomas et al., 2001). It assesses ability to learn and remember spatial locations by drawing on allocentric or survey knowledge. The CG Arena is a computer-based, non-immersive virtual reality task. It is an analogue of Morris's (1984) Water Maze, which is widely used in animal studies of spatial learning. Studies indicate that the constructs measured by the CG Arena correlate well with those measured by the Morris Water Maze, as well as with those proposed by accepted theories of human spatial mapping and navigation (Thomas et al., 2001). In addition, the CG Arena has previously been administered successfully to a sample of autistic children (Edgin & Pennington, 2005).

In the CG Arena task, participants used a joystick to navigate a simulated environment displayed on a personal computer. A circular arena is positioned within a square room. There are sets of distal cues (i.e., pictures) on each wall of the room. These aided the participant in developing a cognitive map of the environment. As the participant viewed the arena from a first-person perspective and moved through it, he/she attempted to locate a square target positioned on the floor of the room. Initially the target was visible to the participants, and in practice trials, they located the target and moved towards it. Each participant had 30 seconds in which to locate and move onto the visible target. Following these trials, participants attempted the experimental condition of the CG Arena task. In this condition, participants entered into the testing room displaying a different set of distal clues (pictures) on its walls. Initially, participants were given 180 seconds to locate the target, which now remained invisible until they moved onto it. After finding the target on this first trial, participants were told that in following trials, the target would remain invisible but that it would be in the same location as on the first trial. Consequently, over four trials, the participant needed to remember the (fixed) location of the hidden target. Each following trial (except the final trial) allowed participants 120 seconds to locate the hidden target. If participants failed to reach the hidden target before the time limit elapsed, the testing programme for that trial would end and they would be placed back into a 'waiting room' before beginning the next trial (Thomas et al., 2001). Figure 3 depicts the four quadrants of the testing room.

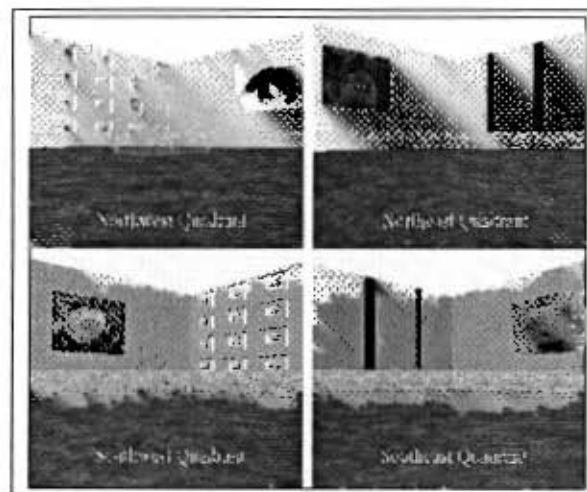


Figure 3. The CG Arena testing room

On the sixth and final trial, although the target was hidden in the same location as in previous trials, it remained hidden even once participants moved onto it. The participants had 90 seconds to search for the target on this trial. Performance on this 'probe' trial is an indication of how well participants remembered the target location, and also served to confirm that participants were purposefully searching for the hidden target and not locating it at random (Thomas et al., 2001). Tables 1 and 2 illustrate the trial parameters of the demonstration and testing phases of the CG Arena, respectively.

Table 1.
CG Arena Demonstration Phase Parameters

Parameter	Demonstration Trial Number			
Trial	1	2	3	4
Start location	N	E	W	S
Target condition	Visible	Visible	Visible	Visible
Target location	SW quadrant	SW quadrant	SE quadrant	Centre
Time limit	30s	30s	30s	30s

Table 2.
CG Arena Testing Phase Parameters

Parameter	Testing Trial Number					
Trial	1	2	3	4	5	6
Start location	E	S	N	W	NE	Centre
Target condition	Invisible	Invisible	Invisible	Invisible	Invisible	Absent
Target location	NW quadrant	NW quadrant	NW quadrant	NW quadrant	NW quadrant	N/A
Time limit	180s	180s	120s	120s	120s	90s

Immediately following completion of the computer task, participants completed the Object Recognition Task (ORT) and then the Arena Reconstitution Task (ART). These tasks assess spatial and non-spatial learning and memory. As such, they provide data that is largely independent of the CG Arena computer portion (Skelton et al., 2000; Thomas et al., 2001; Thomas, 2003).

The ORT is a measure of non-spatial recognition memory. In the ORT, participants were asked to remember which pictures were on the walls of the arena in which they had searched for the hidden target. They did so by choosing pictures from a stimulus card that depicted all of the pictures that were in the room as well as some that were not. This A4-size laminated sheet displayed 16 numbered pictures that were presented in a four-by-four array (see Figure 4). Eight of the 16 pictures present on the card had been displayed on the arena walls during the testing stage. The remaining 8 items were distracters. Participants were asked to indicate by either pointing to the pictures or by responding 'yes' or 'no', whether each item was in the experimental room or not. The number of correct (hits) and incorrect (false positive) pictures chosen by participants were recorded by the researcher.

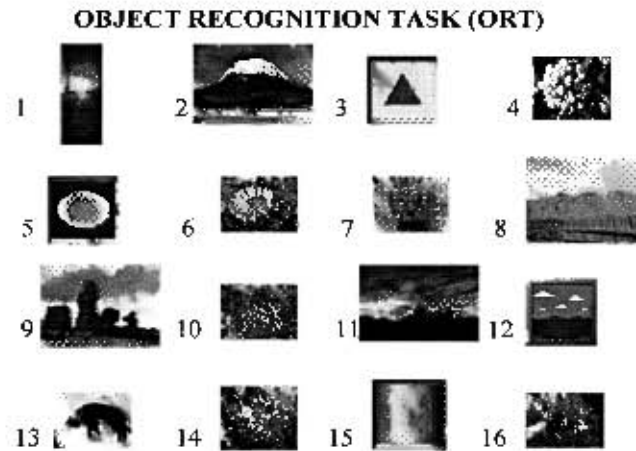
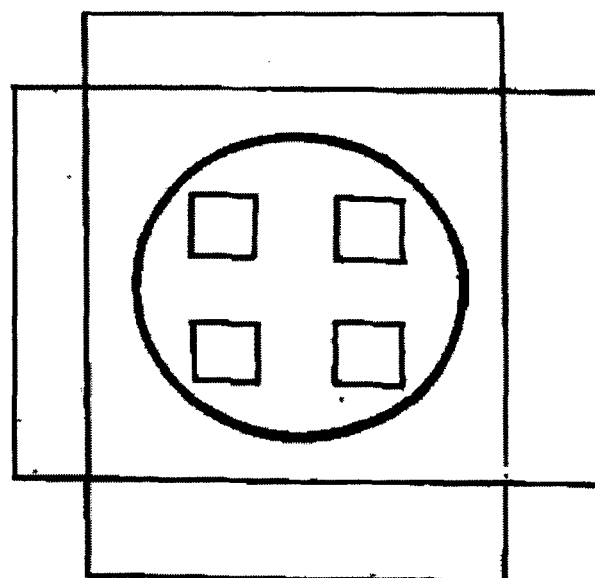


Figure 4. The ORT stimulus card

The ART measures cognitive mapping ability. In the ART, the participant was given the ART stimulus sheet (see Figure 5). The stimulus sheet included a topographic view of the arena testing room, without any detail of the pictures or backgrounds on each wall. The participant was then given four background pieces and eight pictures corresponding to those present in the virtual room. He/she was asked to place each piece on the page in the location they remembered it to be in the virtual arena as if they were building a puzzle. Accordingly, the participant reconstructed the layout of the arena as he/she remembered it. In addition, he/she was asked to indicate which of four squares on the page matched the location of the blue square for which he had been searching. An ART displacement score was determined by calculating the distance each picture had been placed from its correct location. The number of blocks present between the true and reconstituted locations indicated the distance. The ART provides data congruent with the CG Arena itself. Moreover, it informs the strategies that were employed by participants to remember and locate the target object (Skelton et al., 2000; Thomas et al., 2001; Thomas, 2003).



ARENA RECONSTITUTION TASK (ART)

Figure 5. The ART stimulus sheet

Procedure

Each participant and his/her parent(s) received information about the nature of the research. The researcher handed out copies of the information/consent form (See Appendices G and H for these forms for participants in the ASD and non-ASD groups, respectively) to each school. The principal of each AD and mainstream school distributed the forms to each class teacher with the instruction to put the form in each child's school bag with an accompanying note from the school confirming that the study was endorsed by the principal. In the two schools specialising in the education of children with mild learning disabilities from which AS participants were recruited, this procedure differed as not all pupils at the school had AS. In this case, the principal and multi-disciplinary team of speech therapist, occupational therapist, and clinical and/or educational psychologist distinguished which pupils at the school had AS. The principal then distributed the information/consent forms to these pupils' class teachers. In all cases, parents were given a week to respond by returning the completed form to the school. Where children were recruited and assessed independently of any school (i.e. not on school premises or during school hours), permission was obtained from each child's parent(s). In this case, the researcher gave the information/consent form to each parent in person and they were handed back to the researcher in person. Those participants whose parents consented to their taking part completed the battery of cognitive tasks.

The series of tests were administered either at the participant's school or home over two or three sessions, each of which lasted no longer than 50 minutes. Prior to the first testing session, the child's teacher or parent was asked to complete the demographic questionnaire and the Edinburgh Handedness Inventory. The procedure of each testing session was arranged in a semi-structured manner. All the tasks were administered and scored according to the above-mentioned conventions. The testing locations at each school or home were selected to look as similar to the others as possible to reduce the possibility of the environment affecting performance.

The administration procedure was as follows: At the start of the first session, the procedure of the research was briefly described to each participant. Subsequently, the ROCF's copy condition was completed. During five-minute delay required between this measure and the ROCF recall condition, the child undertook the GPT. Next, the CEFT was completed. Following this, the SRL and the SPC tasks were completed. A number of the younger and/or lower functioning children were unable to complete the entire SPC task during the first session due to loss of concentration. When this was the case, the child completed 10 of the 24 trials of this task as well as the SRL task. The remaining 10 trials of the SPC task were then administered during the third session. When this procedure was not necessary, the entire SPC task and the SRL task were completed. For all participants, the second session included the administration of the WASI Performance subtests, the NBMT-CV, and the WCST⁶⁴. The third session comprised the ToL and the CG Arena. For most of the children in the TD control group and the AS group, the second and third sessions were condensed into one session of approximately 50 minutes. This was because they were able to concentrate on the tasks for longer periods and completed many of the tasks more quickly than did other participants.

Participants chose from a collection of stickers on the completion of each task. This served as a reward for participating. It also aided in keeping up their interest.

Data Analysis

All statistical analyses were performed using the SPSS version 15.0 (SPSS Inc., Chicago, IL). The threshold for statistical significance was set at $\alpha = 0.05$ for all decisions.

For many of the analyses outline below, unless otherwise specified in the Results section, *a priori*, simple, planned contrasts and post-hoc multiple comparisons using Bonferroni's correction were employed to investigate statistically significant between-group effects further.

Background Measures

Exact, chi-square tests were used to explore group differences on categorical background measures variables (e.g., sex, handedness, and race). Separate one-way analyses of variance (ANOVAS) were used to assess group differences on continuous background variables (e.g., chronological age, number of drops on the GP, and PIQ).

Demographic Questionnaire

Exploratory analyses of group differences on categorical background measures revealed that on the questions of 'ethnicity' and computer use' on the demographic questionnaire, some categories had frequency counts markedly less than 5. As such, 'ethnicity' was collapsed for the purposes of more accurate analysis to: White, Black, and Other. The category 'Other' included all Coloured, Indian, and Asian participants. Similarly, the original questionnaire categories for 'computer use' were collapsed into the following: Frequently, Sometimes, and Never. The 'Frequently' category included participants who reported using a computer 'every day' or 'once a week', the 'Sometimes' category included participants who reported using a computer 'once a month' or 'a few times a year'. Those participants who reported never using a computer remained in the 'never' category.

Edinburgh Handedness Inventory

The Edinburgh Handedness Inventory score was the number of activities participants' parents/teachers indicated that the child used each hand to complete. If a participant's parent/teacher indicated that the child used his/her right hand on more tasks described on the inventory than his/her left, then he/she was determined to be right-hand dominant. The same procedure applied to left hand dominance and cross-dominance.

WASI

The WASI was scored according to the conventions stipulated in its accompanying test manual (Psychological Corporation, 1999) to determine a measure of PIQ.

GPT

A measure of fine motor manipulation for the dominant hand was determined by counting the number of pegs dropped by the dominant hand during completion of the GPT (D'Andrea & Spiers, 2005).

Executive Function***ToL Total Move Score***

This outcome variable was defined as the sum of the number of moves participants took to complete each problem. This variable therefore provided a measure of overall level of executive planning, including the ability to use supporting cognitive components of attention, response inhibition, working memory, and mental flexibility. Fewer moves indicated a higher level of executive planning. An ANCOVA with chronological age as the covariate was used to explore group differences on this measure.

As Figure 6 illustrates, the remaining scores derived from the measures of EF employed in this research were grouped for analysis according to V. Anderson et al.'s (2001) framework.

<u>COGNITIVE FLEXIBILITY</u>	<u>GOAL SETTING</u>	<u>ATTENTIONAL CONTROL</u>
-ToL Total Correct	-ToL Total Time	-WCST ⁶⁴ Failure to Maintain Set
-ToL Rule Violation	-WCST ⁶⁴ Categories Completed	
-WCST ⁶⁴ Perseverative Errors	-RCF-OSS	

Figure 6. EF outcome variables grouped according to V. Anderson et al.'s (2001) model

Cognitive Flexibility

A multivariate analysis of covariance (MANCOVA), with chronological age as the covariate, was used to determine group differences on the following outcome variables falling under this executive domain.

ToL total correct. This score was the sum of the number of times participants completed each trial in the minimum number of possible moves. This score was used as a measure of working memory capacity and cognitive control. Greater working memory capacity and cognitive control was indicated by a larger number of times a participant was able to complete a problem in the minimum number of moves indicated.

ToL total rule violation. This score was the sum of the number of times participants violated one of the explained rules of the task. These rules were broken when a participant attempted to hold or place a bead so that it was not on a peg, tried to overload smaller pegs with too many beads, or moved more than one bead at a time. This variable therefore provided a measure of the ability to control executive planning in accordance with constraints.

WCST⁶⁴ perseverative errors. Perseverative errors were determined as outlined in the WCST⁶⁴ administration manual (Kongs, et al., 2000); in brief, they were incorrect responses that matched a persevered-to sorting principle. If a participant continued to sort the cards according to, for example, colour, even after that category had been completed and the researcher had given feedback that the sorting principle was incorrect, each subsequent unambiguous and ambiguous error, if sandwiched between two or more unambiguous errors, was scored as a perseverative error. Lower scores indicated fewer perseverative errors and a greater capacity to shift cognitive set.

Goal Setting

A MANCOVA, with chronological age as the covariate, was used to determine group differences on the following outcome variables of goal setting.

ToL total time. This score reflected the total time (in seconds) that participants took to complete the ToL. This variable therefore provided a measure of overall planning as related to problem-solving speed (Culbertson and Zillmer, 2006).

WCST⁶⁴ categories completed. This score (i.e., the number of categories participants were able to complete using the 64 cards given to them) provided an indication of how well participants were able to problem-solve. A category was completed after every 10 responses that correctly matched the sorting principle in use i.e. colour, number, or form.

RCF-OSS. The RCF was scored according to the Rey Complex Figure-Organizational Strategy Score (RCF-OSS; P. Anderson, Anderson, & Garth, 2001) as a measure of EF. Specifically, the copied reproduction of the figure was assessed for organizational approach. The RCF-OSS outlines seven strategies that individuals might use to organize their copies of complex figures. Appendix I outlines the procedure of this system. P.

Anderson et al.'s (2001) scoring system is of particular use as a measure of organizational strategy in paediatric populations. Those researchers used this procedure to generate normative data for the organizational aspect of EF in children between the ages of 7 and 13 years. The system has good inter-rater reliability ($r = .85$ to $.92$) and temporal stability ($r = .79$ to $.94$). The RCF-OSS is sensitive to developmental trends in EF, particularly the initiation and consistency of strategy (P. Anderson et al., 2001).

Attentional Control

An ANCOVA with chronological age as the covariate was used to explore group differences on the WCST⁶⁴ failure to maintain set variable as a measure of 'attentional control'.

WCST⁶⁴ failure to maintain set. This score was the number of times participants failed to complete a category after five or more correct responses. If after five or more correct responses the participant began to sort the cards according to another, incorrect sorting principle, it was marked as a failure to maintain set. Lower scores indicate greater ability to sustain attention.

Visuo-Spatial Ability

The following scores were analysed by separate ANCOVAs with chronological age as the covariate to investigate between-group differences in visuo-spatial ability.

CEFT Score

The CEFT score was the number of times participants correctly identified the embedded figure in the 25 pictures presented on the CEFT. This score provided a measure of 'disembedding'.

BD

Age-adjusted scaled scores for the BD were derived according to the raw score conversion tables in the WASI administration manual (Psychological Corporation, 1999). Higher scaled scores on this measure indicated a greater aptitude for visuo-spatial construction. Participants in the HFA group were not included in the statistical analysis of this measure. This is because this group was not matched by PIQ to any other group in this study. As a subtest of the WASI performance scale, the BD is high-correlated to overall PIQ. It is, however, widely used in ASD research as a measure of visuo-spatial skill (see Hill & Frith, 2006 for a review). As such, participants in the LFA group were compared to PIQ-matched MR controls and AS

participants were compared to PIQ-matched TD controls on this outcome variable to control the confounding effect of intelligence.

ROCF 36-point Copy

The ROCF 36-point copy score was used to assess the accuracy of participants' copied productions of the figure. Specifically, the 18 details of the figure were used to grade the participants' drawings. If a participant drew and placed the details correctly, 2 points were awarded for each detail represented. Points were deducted for incomplete, distorted, and poorly placed reproductions of each detail. This score provided a measure of visuo-spatial construction.

Visuo-Spatial Memory

The following scores were analysed using separate between-group ANCOVAs with chronological age as the covariate.

ROCF 36-point Recall

The participant's recalled reproduction of the ROCF was also scored according to the Rey (1941) 36-point scoring system. The 18 details of the figure were used to grade each participant's free recall drawing of the ROCF 5 minutes after they had initially copied it. Two points were awarded for a correctly placed and complete detail. Points were deducted for incorrect placement or inaccuracy of each detail. This score provided a measure visuo-spatial memory.

CG Arena ORT

To score the ORT, a d-prime (d') score was derived for each participant. D-prime is a commonly used measure of sensitivity in signal detection theories, representing the difference between the means of the Signal Present and Signal Absent distributions. To calculate d' , the participant's hit (H) and false alarm (FA) rates were entered into the following formula: $d' = z(FA) - z(H)$. Specifically, FA and H are the false alarm and hit rates that correspond to right-tail probabilities on the normal distribution, and so therefore $z(FA)$ and $z(H)$ are the standard scores that correspond to the right-tail p -values represented by FA and H. Larger absolute values of d' mean that a person is more sensitive to the difference between the Signal Present and Signal Absent distribution. Values of d' that are near zero indicate chance performance. (See http://wise.cgu.edu/sdtmod/signal_applet.asp for more details.)

Egocentric Spatial Ability

The SRL Task

The SRL was used to investigate egocentric spatial coding. A scale of 1-8 represented the true locations of object placement with each number representing one of eight evenly spaced (by 89mm) true object locations across the middle of the cardboard. The first true object location was 89mm from the right side of the cardboard, 'position 2' represented the second true object location and was 179mm (2x89mm) from the right side of the cardboard and so forth. This task had eight trials. Participants were asked to replace the object as close to its true location as possible once for each of the eight positions. The participants' response location at each true object location was scored as the distance (in mm) from the right side of the cardboard.

In addition, the mean error response at each true object location was calculated by subtracting the participant's response locations (in mm) from the true object location (in mm). For example, if a participant had a response location of 100 mm for position one that had a true object location of 89 mm, his/her error response would be 11 mm (100-89). This would indicate that this participant replaced the object 11 mm to the right of the true object location. Thus, positive errors showed an error bias towards the right of the true object location while negative errors showed an error bias towards the left of the true object location (Huttenlocher, Newcombe, & Sandberg, 1994; Pertini, 2004).

Factorial repeated-measures ANCOVA with age as the covariate was used to determine between-group, location, and interaction effects on this measure.

CG Arena Visible Target Trials

Performance on these trials provided a measure of egocentric spatial ability. The CG Arena programme produces output files on each participant's performance. This file includes information regarding the length of the participant's path from start point to target on each trial, time spent searching for the target and whether the target was found. For analysis, each participant's actual path length to the target on each trial was of interest. Factorial repeated-measures ANCOVA with chronological age as the covariate was used to investigate between-group, trial, and interaction effects on this outcome variable.

Additionally, a one-way ANCOVA with chronological age as the covariate was employed to investigate between-group differences in path length to the target on the final (fourth) visible trial. If participants were able to locate the target effectively by the fourth trial, this was an indication that they had successfully mastered use of the CG Arena equipment and programme.

Allocentric Spatial Ability

SPC Task

The SPC was used to evaluate allocentric place coding. A scale of 1-8 represented the true locations of object placement with each number representing one of eight evenly spaced (by 89mm) true object locations across the middle of the cardboard. The first true object location was 89mm from the right side of the cardboard, 'position 2' represented the second true object location and was 179mm (2x89mm) from the right side of the cardboard and so forth. On each of the 24 trials of this measure, each participant received a response location score, which was the horizontal distance (in mm) from the right side of the cardboard to where they had placed the object on the cardboard. Participants attempted 24 trials during which they would attempt to replace the object as close to one of the eight true object locations as possible. Each true response location was represented three times. The participants' responses for each location were averaged to produce a mean response location.

The true object location in millimetres was subtracted from the participant's response location to create an error response score. On the SPC, poor allocentric spatial ability manifests as a significantly greater systematic bias towards the centre of the cardboard. Moreover, this bias is expected to be larger at locations close to the ends of the cardboard (Huttenlocher, Newcombe, & Sandberg, 1994; Pertini, 2004).

Factorial repeated-measures ANCOVA with age as the covariate was used to determine between-group, location, and interaction effects on this measure.

NBMT-CV

The NBMT-CV derived different outcome variables for each stage of the test procedure (see Appendix F for the NBMT-CV score sheet). The object familiarisation stage of the test was scored as the number of the ten objects participants were able to freely recall a minute after the presentation of these objects. This provided a measure of working memory for objects. An ANCOVA with chronological age as the covariate was used to investigate between-group

effects on this outcome variable. This outcome variable was used as a covariate in subsequent NBMT-CV analyses. This is because between-group differences in working object memory capacity may have significantly influenced performance on the following components of the NBMT-CV.

On the FBMT portion of the NBMT-CV, participants received a score out of 24. A point was awarded for every object freely recalled, object recognised, location recalled, and correct object-location association made by each participant. An ANCOVA with both chronological age and object familiarisation score as covariates was used to investigate between-group effects on this outcome variable.

If participants progressed to the more difficult NBMT-CV, they received a score out of 32. Like the FBMT, a point was awarded for every object freely recalled, object recognised, location recalled, and correct object-location association made by each participant. An ANCOVA with both chronological age and object familiarisation score as covariates was used to investigate between-group effects on this outcome variable.

In addition, a separate ANCOVA with chronological age and object familiarisation score as covariates were used to investigate between-group effects on the number of working objects (objects that were not consistently presented across trials) on the NBMT.

CG Arena Invisible Trials Number of Times Target Found, and ART Score

As mentioned above, the CG Arena programme produces output files containing information on each participant's CG Arena performance. These files indicate the participant's path length to reach the target, whether the target was located, and time spent searching in the correct (NW) arena quadrant for each invisible trial. The following CG Arena outcome variables were analysed using a MANCOVA with chronological age as the covariate.

Targets found. The number of times participants reached the hidden target across trials was calculated by simply summing how many times they were able to locate and reach the hidden target within the given time limit.

Dwell time. On the sixth and final trial of the CG Arena experimental session, the target was absent from the room. The time participants spent searching for the target in the

correct quadrant of the CG Arena indicated how accurately they remembered where the target was located. Thus, the percentage of the total time spent searching for the target in the correct (NW) quadrant of the arena on trial 6 was calculated for each participant. A higher percentage of time indicated more time spent in the correct quadrant and therefore greater certainty of the location of the hidden target.

ART displacement score. An individual displacement score was determined for each of the eight pictures on the ART stimulus sheet by calculating the number of places from the true picture location that the participant replaced his or her picture. These individual scores were then summed to give a total displacement score. Therefore, if a participant obtained a score of zero, he or she had replaced the picture in its true location, a score of one was one place from the true location, and so forth. Lower total displacement scores thus indicated better reconstitutions of the layout of the CG Arena testing room, and better cognitive mapping ability.

CG Arena Invisible Trials Deviation from Optimal Path Length

This CG Arena outcome variable was analysed separately using repeated measures ANCOVA with chronological age as the covariate. As noted earlier in this section, participants completed five experimental trials in the CG Arena. On each of those trials, the target for which they were searching was invisible until they stepped on it. On the first of these five trials participants searched randomly for the target without knowing its location. On trials two to five, the target, although remaining invisible, was in precisely the same location as one trial one. Thus, participants needed to remember where they had found it on the first trial. A deviation from optimal path length was derived by the calculating the difference between participants' actual length to reach the target on each trial and the optimal or minimum path length for each trial. This deviation from optimal path length score indicated how well participants were able to locate the hidden target on each trial. Higher scores indicated a greater difference between actual and optimal path length (i.e., less direct routes to the target), whereas lower scores indicated more direct routes to the target. If adequate spatial learning had taken place, a lower deviation from optimal path length would be expected, particularly as the number of trials completed increased.

Spatial Working Memory

NBMT-CV Working Location Recall

Although the NBMT-CV is primarily a measure of allocentric spatial ability, it includes a sub-measure of spatial working memory. The number of working locations (locations that were not consistently used across trials) that participants were correctly able to identify was subtracted from the total number of locations (both those that remained constant and those that did not) correctly recalled. NBMT-CV working location recall score provided as indication of how well participants were able to recall information stored in spatial working memory.

This NBMT-CV working location recall outcome variable was analysed using an ANCOVA with chronological age and NBMT-CV object familiarisation score as covariates. The latter was included as a covariate as performance on any component of the NBMT-CV could have potentially been influenced by how well the participants were able to engage with and remember the objects used in test.

RESULTS

Background Measures

Group characteristics on categorical variables were explored using separate, exact chi-squared tests. As Table 3 shows, there were statistically significant between-group differences in race and home language. There were, however, no statistically significant between-group differences in handedness, sex, or computer ability. Odds ratios indicated that the ASD (HFA, LFA, and AS) groups were 1.08 times more likely than the control (TD and MR) groups to contain males than females.

Table 3.
Group Differences on Categorical Background Variables

Variable	HFA <i>n</i> = 25	LFA <i>n</i> = 16	AS <i>n</i> = 13	TD <i>n</i> = 22	MR <i>n</i> = 13	Group Differences	
						χ^2	<i>p</i>
Sex						3.14	.547 ^a
Male	21	15	11	16	10		
Female	4	1	2	6	3		
Handedness						10.82	.206 ^a
Right	23	9	11	18	10		
Left	1	4	1	4	2		
Cross	1	3	1	0	1		
Computer use						12.62	.120 ^b
Always	18	11	13	17	7		
Sometimes	2	1	0	3	4		
Rarely/Never	5	4	0	2	2		
Race						25.41	.001 ^{c*}
White	10	7	13	7	4		
Black	9	3	0	4	6		
Other	6	6	0	11	3		
Home language						15.49	.044 [*]
English	15	10	13	20	12		
Afrikaans	4	2	0	1	1		
Other	6	4	0	1	0		

Note. HFA = high-functioning autism; LFA = low-functioning autism; AS = Asperger's syndrome; TD = typically developing; MR = mentally retarded.

^a72% of the cells have an expected count less than 5. ^b66.7% of the cells have an expected count less than 5. ^c40% of the cells have an expected count less than 5.

**p* < .05.

Separate simple one-way ANOVAs were used to explore the continuous background variables: chronological age, GP drops, and PIQ. For each of these variables, Levene's test of homogeneity of variance was significant. Consequently, Welch's *F*-statistic is reported and the Games-Howell procedure for pairwise comparisons when equal variances are not assumed was used. These results, presented in Table 4, indicate significant between-group differences in terms of chronological age and PIQ.

The between-groups differences in PIQ were, of course, expected: The HFA and LFA groups were defined based on that variable, the MR group was recruited as a PIQ control group for

the LFA group, and the TD group was recruited as a PIQ control group for the AS and HFA groups. Therefore, as expected, the LFA and MR groups had equivalent mean PIQ scores ($p = .804$), as did the AS and TD groups ($p = .950$). Also as expected, the HFA group had a significantly higher mean PIQ than the LFA ($p < .001$) and MR ($p = .002$) groups. Unexpectedly, however, the HFA group had a significantly lower mean PIQ than the AS ($p = .002$) and TD ($p < .001$) groups. Consequently, in the subsequent analyses that (a) produced statistically significant between-group differences and where (b) the source of these differences was between the HFA and AS or TD groups, linear regression analyses were conducted to determine how much of this variance in scores could be attributed to PIQ.

The between-groups differences in chronological age were not planned or expected; participants in the AS group were significantly younger than those in all of the other groups simply because those were the participants available for recruitment. Given this situation, chronological age was added as a covariate for many of the following data analyses.

Table 4.

Group Differences on Continuous Background Variables

Variable	HFA (<i>n</i> = 25)	LFA (<i>n</i> = 16)	AS (<i>n</i> = 13)	TD (<i>n</i> = 22)	MR (<i>n</i> = 13)	<i>F</i>	<i>p</i>	Group Differences
Age (years)	10.40 (2.97)	10.87 (2.72)	8.13 (1.40)	10.61 (1.96)	12.14 (2.27)	9.22	< .001**	AS < HFA*, AS < LFA*, AS < TD**, AS < MR**
GP Drops (dominant)	0.88 (1.01)	1.75 (2.32)	0.69 (1.03)	0.45 (0.67)	1.46 (2.73)	1.92	.140	
PIQ	81.71 (7.60)	62.56 (4.38)	100.31 (13.10)	103.25 (14.10)	61.08 (2.84)	96.78	< .001**	LFA < HFA**, LFA < TD**, LFA < AS**, HFA < TD**, HFA < AS**, MR < HFA**, MR < TD**, MR < AS**

Note. HFA = high-functioning autism; LFA = low-functioning autism; AS = Asperger's syndrome; TD = typically developing; MR = mentally retarded. Means are presented with standard deviations in parentheses. All test statistics are based on *df* (4, 84) except Age, which is based on *df* (4, 81) because *n* = 24 for the HFA group and *n* = 20 for the TD group due to some participants being unable to participate in one of the several testing sessions.

* *p* < .05, two-tailed. ** *p* < .01, two-tailed.

Executive Dysfunction

Results for measures within this cognitive domain are shown in Table 5.

Overall Executive Function

ToL Total Moves

Chronological age, the covariate, was significantly related to ToL Move Score, $F(1, 76) = 4.60, p = .035$, partial $\eta^2 = .057$. There were still, however, statistically significant differences in ToL Total Moves scores between participants in the TD and HFA ($t(1, 74) = -2.65, p = .014$) and TD and LFA ($t(1, 74) = -6.44, p < .001$) groups even after controlling for the effect of chronological age. That is to say, participants in the TD group completed the ToL in significantly fewer moves, and, one might infer, therefore showed greater overall EF ability, than participants in both of those ASD groups.

Cognitive Flexibility

ToL Total Correct

The covariate, chronological age, did not significantly influence group performance, $F(1, 76) = 1.10, p = .388$, partial $\eta^2 = .010$. There was a statistically significant between-groups effect on the number of ToL problems participants completed correctly (see Table 5). *A priori* planned contrasts revealed that participants in the TD group performed statistically significantly better than did participants in the LFA group ($t(1, 74) = 3.86, p < .001$) on this ToL outcome variable.

ToL Rule Violation

The covariate chronological age was significantly related to the number of times participants violated ToL rules, $F(1, 76) = 6.78, p = .011$, partial $\eta^2 = .082$. After controlling for this significant effect, however, between-group differences remained statistically significant (see Table 5). *A priori* planned contrasts indicated that participants in the TD group showed significantly fewer ToL rule violations than did participants in the HFA group ($t(1, 74) = 5.45, p < .001$), the LFA group ($t(1, 74) = -5.67, p < .001$), and the MR group ($t(1, 74) = -5.72, p < .001$). Pairwise comparisons using Bonferroni's correction showed that participants in the AS group also showed significantly fewer rule violations than did participants in the LFA ($p = .049$) and MR ($p = .049$) groups.

WCST⁶⁴ Perseverative Errors

Chronological age did not significantly relate to the number of perseverative errors made by participants on the WCST⁶⁴, $F(1, 80) = 0.62, p = .945$, partial $\eta^2 = .0002$. There was, however, a statistically significant between-groups effect with regard to this outcome variable (see Table 5). *A priori* planned comparisons revealed that participants in the TD group made significantly fewer perseverative errors on the WCST⁶⁴ than did participants in the HFA ($t(1, 80) = 3.91, p = .0001$), LFA ($t(1, 80) = 2.94, p = .004$), and MR ($t(1, 80) = 2.51, p = .014$) groups.

Table 5.
Group Differences on Measures of Executive Function (EF)

Domain/Variable	LFA <i>n</i> = 16	HFA <i>n</i> = 24	AS <i>n</i> = 13	MR <i>n</i> = 13	TD <i>n</i> = 20	<i>F</i>	<i>p</i>	Partial η^2
Overall EF								
ToL Total Moves	88.33 (36.76)	55.91 (23.13)	54.27 (18.47)	49.31 (19.25)	37.95 (15.58)	10.94	<.001**	.365
Cognitive Flexibility								
ToL Total Correct	1.40 (1.12)	2.43 (1.50)	3.18 (0.60)	2.62 (1.39)	3.05(1.00)	5.21	.001*	.215
ToL Rule Violation	13.53 (8.37)	11.91 (8.02)	7.55 (6.96)	13.15 (8.48)	0.85 (1.35)	12.50	<.001**	.397
WCST ⁶⁴	21.81 (14.98)	24.00 (11.84)	15.00 (12.35)	21.23 (12.35)	10.50 (3.35)	5.28	.001*	.217
Perseverative Errors								
Goal Setting								
ToL Total Time (seconds)	769.40 (316.59)	567.35 (218.00)	409.64 (154.06)	501.69 (198.09)	296.20 (183.28)	14.78	<.001**	.438
WCST ⁶⁴	0.50 (0.52)	1.25 (0.85)	2.08 (1.44)	1.00 (0.82)	2.70 (0.92)	17.70	<.001**	.482
Categories Completed								
ROCF-OSS	1.73 (0.96)	3.17 (1.40)	2.96 (1.58)	2.23 (1.30)	4.30 (1.45)	15.30	<.001**	.446
Attentional Control								
WCST ⁶⁴	0.50 (1.10)	0.58 (0.83)	0.31 (0.48)	1.00 (1.00)	0.35 (0.59)	2.02	.099	.092
Failure to Maintain Set								

Note. HFA = high-functioning autism; LFA = low-functioning autism; AS = Asperger's syndrome; TD = typically developing; MR = mentally retarded. Means are presented with standard deviations in parenthesis. All test statistics are based on $df(4, 80)$ except ToL Total Moves, ToL Total Correct, ToL Rule Violation, and ToL Total Time, which are based on $df(4, 76)$ because $n = 23$ for the HFA group, $n = 15$ for the LFA group, and $n = 11$ for the AS group due to some participants being unable to participate in one of the several testing sessions.

* $p < .05$, two-tailed. ** $p < .001$, two-tailed.

Goal Setting

ToL Total Time

Chronological age, the covariate for this analysis, had a significant effect on ToL Total Time, $F(1, 76) = 10.93, p = .001$, partial $\eta^2 = .126$. Even after controlling for this covariate, however, a one-way ANOVA still detected a statistically significant between-groups effect on this outcome variable (see Table 5). *A priori* planned contrasts revealed that participants in the TD group solved the ToL problems significantly faster than did participants in the HFA ($t(1, 74) = 4.27, p < .001$), LFA ($t(1, 74) = 7.05, p < .001$), and MR ($t(1, 74) = 3.49, p = .001$) groups. Moreover, post-hoc Bonferroni's pairwise comparisons showed that participants in the LFA group took significantly more time to solve the problems than did participants in the HFA ($p = .009$), AS ($p < .001$), and MR ($p = .021$) groups.

WCST⁶⁴ Categories Completed

Chronological age was significantly related to the number of categories completed by participants, $F(1, 76) = 4.44, p < .001$, partial $\eta^2 = .482$. Even after controlling for this covariate, however, a one-way ANOVA still detected a statistically significant difference between-groups effect on this outcome variable (see Table 5). *A priori* planned comparisons revealed that participants in the TD group completed statistically significantly more WCST⁶⁴ categories than did participants in the HFA ($t(1, 80) = -3.81, p < .001$), LFA ($t(1, 80) = -4.89, p < .001$), and MR ($t(1, 80) = -3.03, p = .003$) groups. Bonferroni's post-hoc pairwise comparisons showed that participants in the AS group also performed statistically significantly better than did participants in the HFA ($p = .021$), LFA ($p < .001$), and MR ($p < .002$) groups on this outcome variable.

RCF-OSS

Chronological age was significantly related to performance on the RCF-OSS, $F(1, 76) = 28.47, p < .001$, partial $\eta^2 = .273$. After controlling for this covariate, a one-way ANOVA still detected a statistically significant between-group effect on the RCF-OSS (see Table 5). On this variable, participants in the TD group performed statistically significantly better than did participants in the LFA ($p = .001$) and MR ($p = .004$) groups. Participants in the HFA group also performed statistically significantly better than did participants in the LFA ($p = .001$) and MR ($p = .009$) groups. Finally, participants in the AS group also had statistically significantly higher scores on this measure than did participants in the LFA ($p = .008$) and MR ($p = .044$) groups.

Attentional Control

WCST⁶⁴ Failure to Maintain Set

There was no statistically significant effect of the covariate chronological age on this outcome variable, $F(1, 80) = 1.98, p = .163$, partial $\eta^2 = .024$. Additionally, a one-way ANOVA detected no statistically significant between-groups effect on this measure (see Table 5).

The Effect of PIQ on EF Performance

As Table 6 indicates, PIQ did not account for a statistically significant amount of the HFA, AS, and TD between-group variance in scores on most measures of EF dysfunction. An exception to this finding was on the ToL rule violations outcome variable; there, PIQ accounted for almost 22% of the between-group variance in scores. Additionally, PIQ also significantly predicted the number of WCST⁶⁴ categories that these groups were able to complete: It accounted for almost 12% of the between-group variance in scores on this outcome variable.

Table 6.

The Effect of PIQ on EF Outcome Variables for the HFA, AS, and TD Groups

Test/Outcome Variable	SE	β	R^2	F	df	p
ToL						
Total Correct	21.86	-.125	.016	0.63	1, 40	.431
Rule Violations	0.61	-.471	.222	11.38	1, 40	.002**
Total Time	2.17	-.276	.076	3.29	1, 40	.077
WCST ⁶⁴						
Perseverative Errors	0.11	-.259	.067	3.09	1, 43	.086
Categories Completed	0.01	.344	.118	5.77	1, 43	.021*

* $p < .05$. ** $p < .001$.

Summary of Results on Measures of Executive Function

In summary, there were no statistically significant between-group differences on the executive domain attentional control.

On all other EF outcome variables, participants in the TD group performed statistically significantly better than did participants in the LFA group. Consequently, one can infer that LFA participants are deficient in overall EF, as well in the sub-domains of cognitive flexibility and goal setting, when compared to TD controls. Compared to PIQ-matched MR controls, however, participants in the LFA group performed equivalently on all EF outcome variables except ToL total time (a measure of goal setting). On this outcome variable, participants in the LFA group performed statistically significantly more poorly than participants in all other groups.

There were no statistically significant differences between participants in the AS group and PIQ-matched TD participants on any of the outcome variables of EF. One can infer, therefore, that AS participants do not display the executive deficits that are predicted by the theory of EF dysfunction.

Participants in the HFA group performed significantly more poorly than the TD group on all outcome variables except ToL total correct as a measure of cognitive flexibility. Participants in the HFA group also performed significantly more poorly than on ToL total moves as a measure of overall EF and WCST⁶⁴ categories completed as a measure of goal setting. On the other outcome variables of EF, even though participants in the HFA group performed more poorly than those in the TD group and the TD group performed equivalently to participants in the AS group, the differences between participants in the AS, and HFA groups did not reach statistical significance.

PIQ accounted for a statistically significant amount of variance in scores between the HFA, AS, and TD groups on ToL rule violations (a measure of cognitive flexibility) and WCST⁶⁴ categories completed (a measure of goal setting). Consequently, although the HFA participants performed more statistically significantly poorly than did participants in both the TD and AS groups on these outcome variables, this statistically significant between-groups effect was significantly confounded by PIQ. In contrast, on all other executive outcome variables, PIQ did not account for a statistically significant amount of variance in scores between these groups. Consequently, one can infer that participants in the HFA group displayed executive deficits compared to TD controls on those outcome variables.

Visuo-Spatial Ability

Results for measures within this cognitive domain are shown in Table 7.

CEFT Score

The covariate, chronological age, had a statistically significant effect on performance on the CEFT, $F(1, 80) = 28.01, p < .0001$, partial $\eta^2 = .259$. Even after controlling for this covariate, a one-way ANOVA still, however, detected a statistically significant between-groups effect on the CEFT score (see Table 7). *A priori* planned comparisons revealed that participants in the TD group performed statistically significantly better than did participants in the HFA ($t(1, 80) = -4.45, p < .001$), LFA ($t(1, 80) = -6.87, p < .001$), and MR ($t(1, 80) = -7.70, p < .001$) groups. Moreover, Bonferroni's pairwise comparisons revealed that participants in the HFA group performed statistically significantly better than did participants in the LFA ($p < .001$) and MR ($p < .001$) groups. Additionally, participants in the AS group performed statistically significantly better than participants in the HFA ($p = .016$), LFA ($p < .001$), and MR ($p < .001$) groups.

ROCF 36-pt Copy

Chronological age was a significant covariate in this analysis, $F(1, 80) = 40.15, p < .0001$, partial $\eta^2 = .334$. Even after controlling for this covariate, however, a one-way ANOVA still detected a statistically significant between-groups effect on ROCF 36-pt Copy performance (see Table 7). *A priori* planned contrasts revealed that participants in the TD group had statistically significantly higher scores on this outcome variable than did participants in the HFA ($t(1, 80) = -4.71, p < .001$), LFA ($t(1, 80) = -8.79, p < .001$), and MR ($t(1, 80) = -7.85, p < .001$) groups. Moreover, post-hoc Bonferroni's pairwise comparisons showed that participants in the HFA group performed statistically significantly better than did participants in the LFA ($p < .001$) and MR ($p = .001$) groups. Similar analyses showed that participants in the AS group also performed statistically significantly better than participants in the HFA ($p = .016$), LFA ($p < .001$), and MR ($p < .001$) groups.

BD Subtest

Age was not added as a covariate for this analysis as BD scaled scores were used. A one-way ANOVA detected a statistically significant between-groups effect on BD subtest performance (see Table 7). Post-hoc pairwise comparisons using Bonferroni's correction indicated that participants in the TD and AS groups performed significantly better than those in the MR (p

$< .001$) and LFA ($p < .001$) groups. *A priori* planned comparisons revealed, however, no statistically significant differences between participants in the AS group and those in the PIQ-matched TD group ($t(1, 60) = -0.03, p = 0.98$). Similarly, there were no statistically significant differences between participants in the LFA and those in the MR group ($t(1, 60) = -0.05, p = 0.96$) on this outcome variable.

The Effect of PIQ on Visuo-Spatial Ability

As Table 8 shows, PIQ did account for a significant amount of the variance in scores between participants in the HFA, AS, and TD groups on the CEFT and ROCF 36-pt Copy. PIQ predicted 30% of the between-groups variance in scores on the ROCF 36-pt Copy and 22% of the variance in scores on the CEFT.

Summary of Results on Measures of Visuo-Spatial Ability

The theory of WCC posits that individuals with ASD will outperform non-autistic controls on visuo-spatial measures. In this research, participants in the TD and AS groups performed consistently better than participants in the HFA, LFA, and MR groups on measures of visuo-spatial ability. PIQ did, however, account for a statistically significant amount of the variance in scores between participants in the HFA, AS, and TD groups on the CEFT and the ROCF 36-pt copy. There were no statistically significant differences between participants in the PIQ-matched LFA and MR groups or between participants in the PIQ-matched TD and AS groups. Consequently, no visuo-spatial strength was replicated.

Table 7.
Group Differences on Visuo-Spatial Measures

Variable	LFA <i>n</i> = 16	HFA <i>n</i> = 24	AS <i>n</i> = 13	MR <i>n</i> = 13	TD <i>n</i> = 20	<i>F</i>	<i>p</i>	Partial η^2
Visuo-spatial Ability								
CEFT Score	7.38 (4.11)	11.25 (6.06)	11.92 (6.17)	6.54 (6.15)	17.70 (3.84)	19.86	< .001**	.498
ROCF 36-pt Copy	5.16 (6.51)	16.67 (12.68)	20.92 (12.76)	9.08 (8.58)	29.05 (7.71)	28.27	< .001**	.586
BD	27.94 (2.79)		52.08 (8.46)	28.08 (2.78)	52.00 (10.70)	52.71	< .001**	.711

LFA = low-functioning autism; HFA = high-functioning autism; AS = Asperger's syndrome; MR = mentally retarded; TD = typically developing. Means are presented with standard deviations in parenthesis. All test statistics are based on *df* (4, 80) except BD, which is based on *df* (3, 60) because the HFA group's scores were not included in the analysis to control for the erroneous influence of PIQ.

***p* < .001, two-tailed.

Table 8.
The Effect of PIQ on Visuo-Spatial Ability for the HFA, AS, and TD Groups

Test/Outcome Variable	SE	β	<i>R</i> ²	<i>F</i>	<i>df</i>	<i>p</i>
CEFT Score	.053	.473	.224	12.42	1,43	.001*
ROCF 36-pt Copy	.096	.546	.298	19.08	1,45	< .001**

p* < .01. *p* < .001.

Visuo-Spatial Memory

ROCF 36-pt Recall

The covariate, chronological age, was significantly related to ROCF 36-pt recall, $F(1, 80) = 13.25, p < .0001$, partial $\eta^2 = .142$. Even after the covariate had been introduced, there was still, however, a statistically significant between-groups effect on performance on this outcome variable (see Table 9). *A priori* planned comparisons showed that participants in the TD group performed statistically significantly better than did participants in the HFA ($t(1, 80) = -4.93, p < .001$), LFA ($t(1, 80) = -7.34, p < .001$), and MR ($t(1, 80) = -6.35, p < .001$) groups. Additionally, Bonferroni's pairwise comparisons revealed that participants in the HFA group performed statistically significantly better than did participants the LFA group ($p = .036$). Participants in the AS group performed statistically significantly better than did participants in the LFA ($p < .001$) and MR ($p = .002$) groups.

ORT

The covariate, chronological age, was not significantly related to ORT performance, $F(1, 85) = 0.49, p = .485$, partial $\eta^2 = .006$. As indicated in Table 9, there was also no statistically significant between-groups effect on ORT score.

The Effect of PIQ on Visuo-Spatial Memory

As Table 10 indicates, PIQ did account for a statistically significant amount of the variance in scores between participants in the HFA, AS, and TD groups on the ROCF 36-pt recall. On this outcome variable, PIQ determined almost 24% of the variance in scores.

Summary of Results on Measures of Visuo-Spatial Memory

On the ORT, all the groups performed equivalently. Thus one can infer that on this measure, all ASD participants performed similarly to non-ASD participants and display intact visuo-spatial memory. On the ROCF 36-pt recall, participants in the AS group performed equivalently to those in the TD group suggesting that in this ASD population visuo-spatial memory is intact in comparison to PIQ-matched controls. Similarly, there were no statistically significant differences between participants in the LFA group and those in the MR group. The difference in scores between the HFA and AS participants did not reach statistical significance. Participants in the TD group, however, performed significantly better on this outcome variable than the HFA participants. A linear regression analysis of the effect

of PIQ on differences between participants in the AS, TD, and HFA groups on this outcome variable, was, however, also statistically significant. Consequently, the HFA participants poor performance compared to the TD participants was not solely determined by them having ASD.

University of Cape Town

Table 9.

Group Differences on Measures of Visuo-Spatial Memory

Variable	HFA <i>n</i> = 24	LFA <i>n</i> = 16	AS <i>n</i> = 13	MR <i>n</i> = 13	TD <i>n</i> = 20	<i>F</i>	<i>df</i>	<i>p</i>	Partial η^2
ROCF 36-pt Recall	7.52 (8.00)	1.81 (2.76)	10.77 (8.44)	4.19 (3.97)	17.30 (71.89)	18.01	4, 80	<.001**	.474
ORT (<i>d'</i> score)	1.64 (1.72)	1.58 (1.41)	1.80 (0.86)	1.50 (1.47)	2.11 (0.66)	0.87	4, 85	.485	.042

Note. HFA = high-functioning autism; LFA = low-functioning autism; AS = Asperger's syndrome; MR = mentally retarded; TD = typically developing. Means are presented with standard deviations in parentheses.

***p* < .001, two-tailed.

Table 10.

The Effect of PIQ on Visuo-Spatial Memory for the HFA, AS, and TD Groups

Test/ Outcome Variable	SE	β	R^2	<i>F</i>	<i>df</i>	<i>p</i>
ROCF 36-pt Recall	.070	.486	.236	15.45	1, 50	<.001**

***p* < .001.

Egocentric and Allocentric Spatial Abilities

Egocentric Spatial Abilities

SRL Task

To test the metric accuracy of the sample's response locations, a repeated-measures ANCOVA was conducted to investigate the effect each true object location had on the participant's response location. Mauchly's test of sphericity was statistically significant, indicating heterogeneity of covariance. Consequently, corrected F -Values using Greenhouse-Geisser estimates ($\epsilon = .41$) are presented.

Results were statistically significant, $F(2.83, 237.90) = 10.79, p < .000$, partial $\eta^2 = 0.114$, for the between-location effect but not for the covariate chronological age, $F(2.83, 237.90) = 0.93, p = .421$). *A priori* planned comparisons revealed that the mean response location for each true object location was significantly different from the next closest mean response location. This indicated that the sample's mean response locations were systematically related to the true response location.

This procedure was also carried out for each group. Table 11 displays, and Figure 7 illustrates, each group's mean response location at each true location. Figure 7 suggests that the AS participants were able to replace the object most accurately. Their mean response location is most similar to the true object location according to Figure 7. Figure 7 also suggests that participants in the TD group consistently replaced the figurine used in the SRL task closer towards the edges of the cardboard on locations not in the centre of the cardboard (i.e. P4) or on the edges of the cardboard (i.e. P1 and P8). This is because their mean response locations were fewer millimetres from the left hand side of the board than the true object location at locations towards the left of the midpoint (P4) of the space. Conversely, at locations closer to the right side of the midpoint (P4) of the cardboard, participants in the TD group replaced the object further from the centre (at 400 mm) and closer towards edge of the cardboard than was necessary. For the other groups of participants in this study this pattern is reversed. As the figure shows, the MR and more so the HFA and LFA participants tended to replace the object towards the centre (at 400 mm) of the continuous space at locations further from the midpoint (P4).

Table 11.

SRL Group Mean Response Locations

True Object Location	HFA <i>n</i> = 25	LFA <i>n</i> = 16	AS <i>n</i> = 13	TD <i>n</i> = 22	MR <i>n</i> = 13
P1(89mm)	191.16 (113.25)	202.25 (142.05)	139.38 (116.53)	87.09 (38.55)	224.77 (177.15)
P2(178mm)	240.96 (98.52)	232.19 (96.02)	184.00 (112.15)	142.64 (43.70)	205.77 (59.09)
P3(267mm)	307.88 (81.08)	317.50 (85.55)	308.23 (62.73)	255.36 (42.56)	273.15 (118.14)
P4(356mm)	358.04 (78.45)	373.00 (109.19)	385.31 (57.46)	365.64 (54.69)	391.85 (76.64)
P5(445mm)	410.28 (115.64)	459.69 (72.43)	461.62 (46.49)	484.32 (63.59)	429.46 (120.63)
P6(534mm)	512.68 (114.90)	502.13 (134.93)	540.54 (84.42)	589.55 (61.94)	560.38 (78.33)
P7(623mm)	542.12 (174.07)	563.44 (129.61)	651.85 (83.38)	679.05(48.90)	604.85 (160.62)
P8(712mm)	599.96 (165.94)	592.44(137.01)	725.62(63.44)	736.82(41.05)	655.08 (125.04)

Note. HFA = high-functioning autism; LFA = low-functioning autism; AS = Asperger's syndrome; TD = typically developing; MR = mentally retarded. All means and standard deviations (SD) are reported in millimetres.

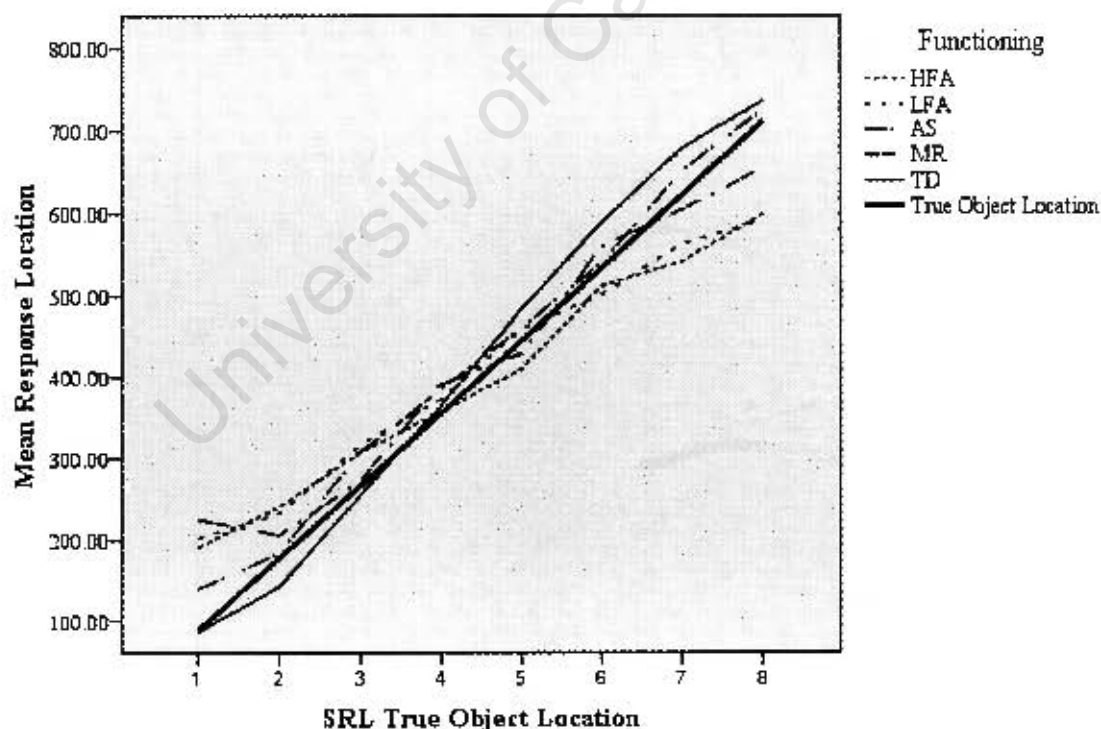


Figure 7. Diagrammatic representation of SRL group mean response locations

The separate ANCOVAS for each group to determine whether the groups' mean response locations were systematically related to the true response location indicated that for all the groups, the covariate chronological age did not exert a significant effect on mean response location. For the TD group, Mauchly's test of sphericity was statistically significant indicating heterogeneity of covariance, $w(27) = 0.06, p = .020$, so F -values based on Greenhouse-Geisser estimates ($\epsilon = .54$) are reported. There was the expected statistically significant effect of true object location on mean response location, $F(3.78, 67.98) = 15.79, p < .001$, partial $\eta^2 = .467$. Consequently, one can conclude that participants in the TD group produced response locations that were systematically related to the true response locations.

For the HFA group, Mauchly's test of sphericity was statistically significant, $w(27) = 0.02, p < .001$. Consequently, F -values using Greenhouse-Geisser estimates ($\epsilon = .47$) are reported. For participants in this group, unlike those in the TD group, there was no statistically significant effect of true object location on response location, $F(3.32, 73.02) = 0.54, p = .674$, partial $\eta^2 = .024$. Similarly, for participants in the LFA group, there was also a statistically non-significant effect of true object location on response location, $F(7, 98) = 1.64, p = .135$, partial $\eta^2 = .105$.

Mauchly's test of sphericity was statistically significant for the AS group, $w(27) = 0.00, p < .001$. Hence, F -values adjusted using Greenhouse-Geisser estimates ($\epsilon = .33$) are reported. There was also no statistically significant effect of true object location on mean response locations, $F(2.33, 25.59) = 1.28, p = .272$, partial $\eta^2 = .104$, for participants in this group.

Mauchly's test of sphericity was also significant for the MR group, $w(27) = 0.00, p = .020$. Consequently, F -values using Greenhouse-Geisser estimates ($\epsilon = .54$) are reported. There was no statistically significant effect of true object location on participants in the MR group's response locations, $F(2.14, 23.57) = 0.38, p = .704$, partial $\eta^2 = .157$.

Table 12 shows the mean error response for each group. A repeated-measures ANCOVA was conducted to assess the effect of true object location on the absolute mean error response for each group. For the HFA group, Mauchly's test of sphericity was statistically significant, $w(27) = 0.10, p = .021$. Consequently, F -values corrected using Greenhouse-Geisser estimates ($\epsilon = .68$) are reported. The covariate, chronological age, was statistically non-significant, $F(4.73, 104.02) = .431, p = .816$, partial $\eta^2 = .019$. There was no statistically

significant effect of true object location on the size of absolute error responses for participants in the HFA group, $F(4.73, 104.02) = 1.16, p = .335$, partial $\eta^2 = .050$. This piece of data implies that there was a statistically significant difference in absolute error bias across the eight true object locations.

For the LFA group, Mauchly's test of sphericity was statistically significant, $w(27) = 0.02, p = .019$, indicating heterogeneity of covariance. Consequently, F -values using Greenhouse-Geisser estimates ($\epsilon = .51$) are reported. The covariate, chronological age, was not statistically significant, $F(3.57, 49.95) = 0.15, p = .949$, partial $\eta^2 = .011$. There was also no statistically significant effect of true object location on absolute error responses for participants in this group across locations, $F(3.57, 49.95) = 0.11, p = .970$, partial $\eta^2 = .008$.

For the AS group, Mauchly's test of sphericity was statistically significant, $w(27) < .001, p < .001$. Consequently, Greenhouse-Geisser ($\epsilon = .318$) corrected F -values are reported. The covariate chronological age was not statistically significant, $F(2.22, 24.48) = 0.59, p = .582$, partial $\eta^2 = .050$. There was also no statistically significant effect of true object location on absolute response errors across locations, $F(2.22, 24.48) = 0.68, p = .533$, partial $\eta^2 = .058$.

For the MR group, Mauchly's test of sphericity was statistically significant, $w(27) = 0.001, p < .001$ so F -values using Greenhouse-Geisser estimates ($\epsilon = .39$) are reported. There was also no statistically significant relationship between absolute error response and the covariate, chronological age, for participants in the MR group, $F(2.70, 29.67) = 0.81, p = .488$, partial $\eta^2 = .068$. There was no statistically significant effect of true object location on absolute error responses for participants in this group, $F(2.70, 29.67) = 0.65, p = .572$, partial $\eta^2 = .056$.

Table 12.

SRL Group Mean Response Error

True Object Location	HFA <i>n</i> = 25	LFA <i>n</i> = 16	AS <i>n</i> = 13	TD <i>n</i> = 22	MR <i>n</i> = 13	<i>F</i>	<i>p</i>	Partial η^2
P1(89mm)	104.54 (115.05)	113.25 (142.05)	50.38 (116.53)	-1.20 (40.35)	135.77 (177.15)	4.14	.004**	.172
P2(178mm)	58.17 (97.61)	54.19 (96.02)	6.00 (112.15)	-35.15 (44.02)	27.77 (59.08)	4.13	.004**	.171
P3(267mm)	44.58 (80.63)	50.50 (85.55)	41.23 (62.73)	-8.80 (42.93)	6.15 (118.14)	1.80	.137	.083
P4(356mm)	1.83 (80.13)	17.00 (109.19)	29.31 (57.46)	6.20 (55.92)	35.85 (76.47)	.600	.663	.029
P5(445mm)	-30.13 (115.77)	14.69 (72.43)	16.61 (46.49)	41.50 (66.40)	-15.54 (120.63)	2.05	.095	.093
P6(534mm)	-16.63 (114.89)	-31.88 (134.93)	6.53 (84.42)	54.40 (64.61)	26.38 (78.33)	2.21	.075	.100
P7(623mm)	-75.21 (175.44)	-59.56 (129.61)	28.85 (83.38)	57.30 (48.08)	-18.15 (160.62)	3.91	.006**	.164
P8(712mm)	-116.13 (168.22)	-119.56 (137.01)	13.62 (63.44)	21.00 (40.35)	-56.92 (125.04)	5.81	< .001**	.225

Note. HFA = high-functioning autism; LFA = low-functioning autism; AS = Asperger's syndrome; TD = typically developing; MR = mentally retarded. All means and standard deviations (SD) are reported in millimetres. All test statistics are based on *df*(4, 80).

** *p* < .01, two-tailed.

For the TD group, Mauchly's test of sphericity was statistically significant indicating heterogeneity of variance, $w(27) = 0.05, p = .011$. As a result, Greenhouse-Geisser ($\epsilon = .61$) corrected F -values are reported. The covariate, chronological age, was statistically non-significant, $F(4.25, 76.40) = 1.04, p = .394$, partial $\eta^2 = .055$. As for all of the other groups, there was no statistically significant effect of true object location on mean error response.

A MANCOVA was conducted to investigate group differences in mean error response for the various true object locations. The covariate for this analysis, chronological age, was statistically non-significant for all the locations except location 3, $F(1, 80) = 4.51, p = .037$, partial $\eta^2 = .053$. There were statistically significant between-group differences in error responses on the first, second, seventh, and eighth true object locations (see Table 12). *A priori* planned contrasts revealed that at true location 1, participants in the TD group had a significantly lower error response than did participants in the MR group ($t(1, 82) = 3.48, p = .029$). Post-hoc pairwise comparisons showed that participants in the TD group also performed statistically significantly better than did participants in the LFA ($p = .049$) group. At position 2, post-hoc pairwise comparisons revealed that participants in the TD group performed significantly better than did participants in the HFA ($p = .006$) and LFA ($p = .023$) groups. At position 7, *a priori* planned contrasts showed that participants in the TD group performed statistically significantly better than did participants in the HFA ($t(1, 82) = 3.64, p < .001$) and LFA ($t(1, 82) = 2.81, p = .006$) groups. Similarly, at this position, participants in the AS group had significantly lower error responses than did participants in the HFA ($t(1, 82) = 2.67, p = .001$) and LFA ($t(1, 82) = 2.09, p = .039$) groups.

Summary of results on the SRL. On the SRL, only participants in the TD group replaced the object systematically towards the true object location as revealed by the statistically significant effect of true object location on response location for this group. For the other participants there was, however, no significant effect of true object location on response location. Consequently, these participants were not systematically replacing the object near its true location. This suggests that these participants may have been placing the object at random locations on the cardboard. Thus, any further results should be interpreted with caution. Further analyses revealed, however, that all the participants showed a consistent level of bias across all locations. In terms of group differences in performance on this task, the only statistically significant differences between groups were on locations one, two, seven, and eight. These differences were between either HFA, LFA, or MR participants and

TD participants. There were no statistically significant differences between participants in the AS and TD groups.

CG Arena Visible Trials

On the factorial repeated-measures ANCOVA with chronological age as the covariate used to investigate between-group, trial, and interaction effects on this outcome variable, there was no statistically significant between-group effect of the covariate, chronological age, on this outcome variable, $F(1, 78) = 0.44, p = .512$, partial $\eta^2 = .006$. Conversely, there was a statistically significant main effect of trial on performance on the visible trials of the CG Arena, $F(2.50, 195.18) = 4.05, p = .012$, partial $\eta^2 = .049$. *A priori* within-subject contrasts revealed that path lengths to the target were significantly shorter on trial 4 compared to trial 1 ($t(1, 81) = 6.38, p < .001$), trial 2 ($t(1, 81) = 9.26, p < .001$), trial 3 ($t(1, 81) = 8.03, p < .001$). There was no statistically significant group x trial interaction, $F(10.00, 195.18) = 1.70, p = .084$, partial $\eta^2 = .080$. As illustrated in Figure 8, there was, however, a statistically significant main effect of group on the CG Arena visible trials, $F(4, 78) = 5.23, p = .001$, partial $\eta^2 = .211$. *A priori* planned comparisons revealed that participants in the TD group performed statistically significantly better than did participants in the HFA ($t(1, 81) = 3.08, p = .003$), LFA ($t(1, 81) = 2.73, p = .008$), and MR ($t(1, 81) = 3.68, p < .001$) groups.

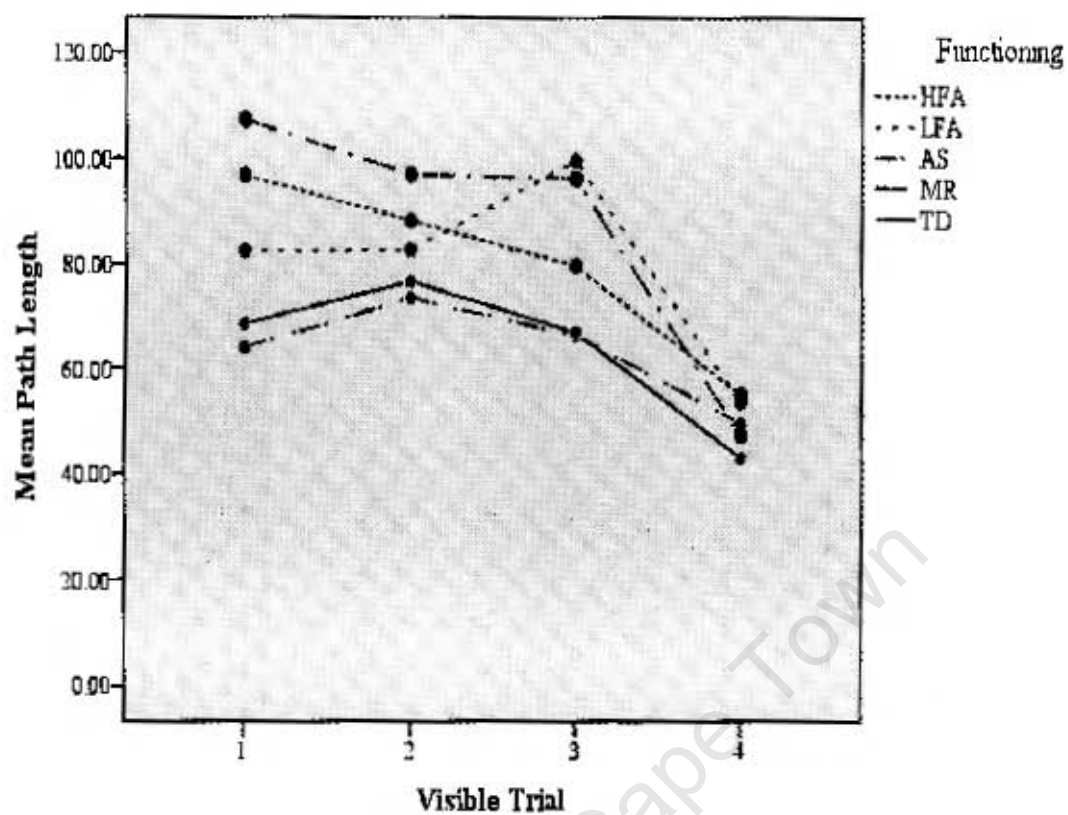


Figure 8. Mean path length across CG Arena visible trials

Table 13.
Scores on CG Arena Outcome Variables

Variable	HFA <i>n</i> = 24	LFA <i>n</i> = 16	AS <i>n</i> = 12	TD <i>n</i> = 22	LD <i>n</i> = 13
Visible Target					
Trial 1	96.74 (46.67)	81.95 (37.49)	67.74 (2.05)	68.41 (4.57)	104.88 (51.88)
Trial 2	88.15 (19.77)	82.50 (21.85)	74.36 (0.78)	76.61 (8.72)	96.26 (0.78)
Trial 3	79.72 (21.77)	99.04 (46.11)	69.36 (6.91)	66.79 (0.61)	66.79 (0.61)
Trial 4	54.98 (42.73)	54.01 (22.93)	47.72 (15.38)	43.13 (0.26)	48.48 (15.11)
Deviated Path Length					
Trial 1	298.88 (237.22)	391.66 (276.31)	466.18 (290.78)	292.71 (263.64)	492.45 (239.49)
Trial 2	308.82 (249.08)	344.91 (225.64)	136.22 (139.78)	283.98 (263.64)	217.44 (214.05)
Trial 3	265.11 (216.05)	437.83 (216.05)	170.40 (142.44)	188.61 (168.97)	303.75 (234.18)
Trial 4	283.10 (319.39)	408.13 (233.76)	173.52 (132.85)	139.10 (157.92)	320.51 (215.83)
Trial 5	312.84 (255.57)	256.83 (232.47)	245.83 (195.05)	185.94 (187.56)	346.84 (263.75)
Dwell time	31.96 (20.99)	28.55 (18.21)	56.37 (26.62)	60.07 (26.58)	29.21 (16.43)
Target Crossings	4.54 (0.66)	4.00 (0.73)	4.17 (0.83)	4.68 (0.65)	4.62 (0.51)
ART	23.17 (04.82)	24.50 (04.58)	16.75 (06.30)	15.95 (07.93)	23.00 (05.64)

Note. HFA = high-functioning autism; LFA = low-functioning autism; AS = Asperger's syndrome; TD = typically developing; MR = mentally retarded. Means are presented with standard deviations in parenthesis.

To test whether participants had successfully mastered the use of the CG Arena equipment and programme, a separate one-way ANCOVA of mean path length on the final visible trial, trial 4, was conducted. On this analysis, there was no statistically significant effect of the covariate, chronological age, on path length, $F(1, 78) = 0.33, p = .568$, partial $\eta^2 = .004$. Moreover, there was no statistically significant between-groups effect on performance on this trial, $F(4, 78) = .674, p = .612$, partial $\eta^2 = .033$. From this analysis, one can infer that even though the HFA, LFA, and MR participants look longer to find the visible target using egocentric spatial processing on the first three trials, by the fourth and final trial they had successfully learned how to use the CG Arena apparatus and had formulated an

understanding of how to complete the task. Consequently, these participants proved able to continue to the invisible trials of the CG Arena.

The Effect of PIQ on Egocentric Spatial Ability

Table 14 indicates the results of a linear regression analysis used to determine the influence of PIQ on egocentric spatial ability. PIQ accounted for a statistically significant amount of the variance in scores between the HFA, AS, and TD groups on the measures of egocentric spatial ability. This means that any statistically significant between-group differences on these outcome variables are significantly attributable to differences in intellectual ability.

Table 14.

The Effect of PIQ on Egocentric Spatial Ability for HFA, AS, and TD Groups

Test/ Outcome Variable	SE	β	R^2	F	df	p
SRL Task	.352	-.409	.167	10.02	1,50	.003*
CG Arena Visible Trials	.142	-.478	.228	14.18	1,48	<.001**

* $p < .05$. ** $p < .001$.

Summary of Results of Egocentric Spatial Ability

There were no statistically significant differences between participants in the PIQ-matched AS and TD groups. Thus, although intact egocentric spatial ability was expected of all ASD participants, only those in the AS group showed such ability. It appears that level of intellectual functioning played an important role in performance on these tasks: First, there were no statistically significant differences in performance on egocentric spatial tasks between participants in the LFA group and those in the PIQ-matched MR group. Second, participants in the HFA group performed significantly more poorly than did those in the TD and AS groups on these tasks, and PIQ significantly predicted the variance in scores between those three groups.

Allocentric Spatial Ability

SPC Task

To test the metric accuracy of the sample's response locations, a repeated-measures ANCOVA was conducted to investigate the effect each true object location had on participant's response locations. Mauchly's test of sphericity was significant indicating heterogeneity of covariance, $w(27) = 0.04$, $p < .001$. Consequently, corrected F -Values using

Greenhouse-Geisser estimates ($\epsilon = .40$) are reported. Results were statistically significant for the main effect of group but not the covariate chronological age, $F(2.82, 228.75) = 14.46, p < .001$, partial $\eta^2 = .151$, and $F(2.82, 228.75) = 0.86, p = .457$, partial $\eta^2 = .010$, respectively. Post-hoc pairwise comparisons revealed that the mean response location for each true object location was significantly different from the next closest mean response location. This set of data thus indicates that the sample's mean response locations were systematically related to the true response location.

The above procedure was also carried out in a separate analysis for each group. Table 15 displays and Figure 9 illustrates the groups' mean response locations at each true object location. For the participants in all groups, except participants in the AS group, $F(7, 70) = 3.06, p = .007$, partial $\eta^2 = .234$, chronological age did not significantly relate to mean response location.

For participants in the TD, AS, and MR groups, true object location had the expected significant effect on mean response location ($F(7, 126) = 15.63, p < .001$, partial $\eta^2 = .465$; $F(7, 70) = 6.12, p < .001$, partial $\eta^2 = .380$; $F(7, 77) = 2.34, p = .032$, partial $\eta^2 = .176$). Mauchly's test of sphericity was significant for the HFA group, $w(27) = 0.03, p < .001$. Consequently, F -values based on Greenhouse-Geisser estimates ($\epsilon = .415$) are reported. True object location had no statistically significant effect on mean response location for this group, $F(7, 63.92) = 1.13, p = .344$, partial $\eta^2 = .049$. Similarly, true object location did not significantly effect mean response location for participants in the LFA group, $F(7, 84) = 0.62, p = .736$, partial $\eta^2 = .049$.

Table 15.

SPC Group Mean Response Location

True Object Location	IIFA <i>n</i> = 24	LFA <i>n</i> = 14	AS <i>n</i> = 12	TD <i>n</i> = 20	MR <i>n</i> = 13
P1(89mm)	211.97 (129.19)	235.57 (110.59)	101.11 (36.83)	111.20 (36.63)	161.85 (111.10)
P2(178mm)	216.15 (76.04)	297.21 (79.82)	180.02 (50.03)	181.03 (36.86)	233.46 (94.87)
P3(267mm)	303.92 (90.10)	380.12 (85.14)	252.00 (39.68)	298.28 (56.41)	359.62 (111.86)
P4(356mm)	385.19 (65.43)	390.50 (85.00)	362.72 (47.52)	370.05 (41.75)	430.85 (77.20)
P5(445mm)	404.90 (93.55)	413.43 (81.29)	452.06 (50.27)	460.87 (48.38)	425.90 (70.40)
P6(534mm)	511.68 (92.74)	462.79 (91.77)	578.42 (51.65)	554.65 (39.70)	522.62 (101.31)
P7(623mm)	502.74 (131.23)	471.93 (119.53)	607.08 (95.14)	643.65 (28.72)	576.00 (80.28)
P8(712mm)	606.93 (106.59)	541.10 (137.91)	687.89 (76.33)	715.03 (38.71)	651.62 (92.44)

Note. HFA = high-functioning autism; LFA = low-functioning autism; AS = Asperger's syndrome; TD = typically developing; MR = mentally retarded. All means and standard deviations (SD) are reported in millimetres.

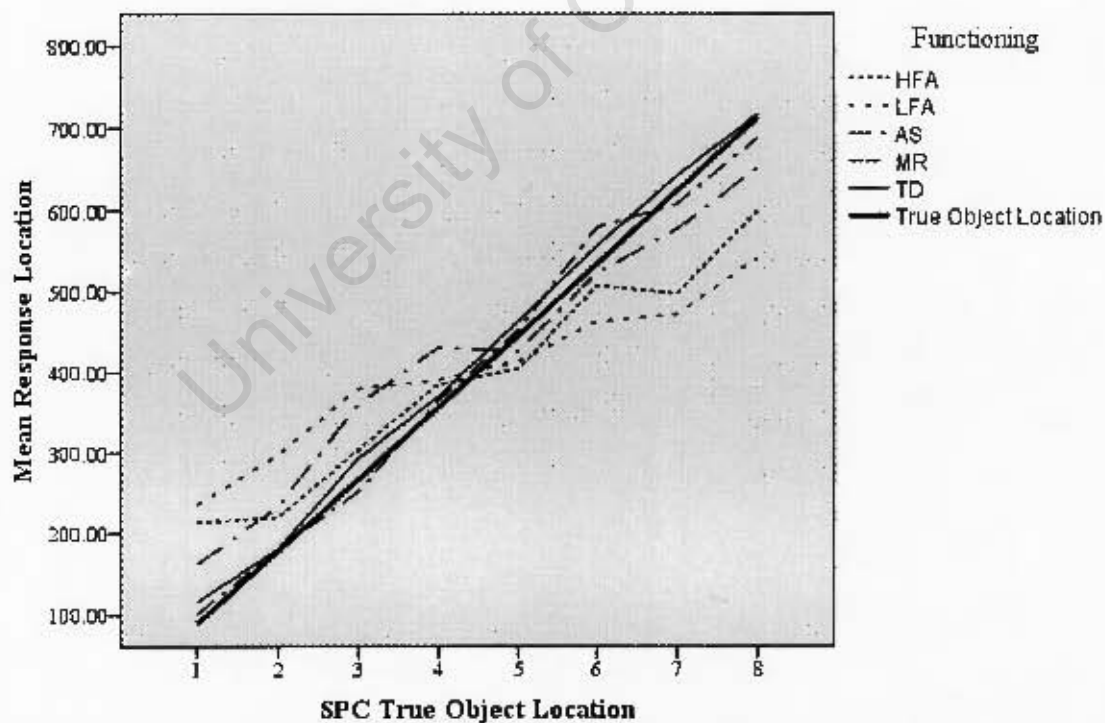


Figure 9. Diagrammatic representation of SPC group mean response locations

A repeated-measures ANCOVA of the effect of true object location on the absolute mean error response was performed for each group. The covariate, chronological age, was statistically non-significant for participants in the TD group, $F(7, 126) = 0.78, p = .605$, partial $\eta^2 = .042$. True object location also had no statistically significant effect on absolute error responses for participants in the TD group, $F(7, 126) = 0.77, p = .612$, partial $\eta^2 = .041$. Mauchly's test of sphericity was statistically significant for the AS group, $w(27) = 0.001, p = .013$. Consequently, F -values corrected by Greenhouse-Geisser estimates ($\epsilon = .45$) are reported. Chronological age did not significantly relate to absolute error responses for participants in this group, $F(3.13, 31.33) = 1.49, p = .235$, partial $\eta^2 = .130$. There was also no statistically significant effect of true object location on mean absolute error response for participants in this group, $F(3.13, 31.33) = 1.44, p = .250$, partial $\eta^2 = .126$.

Mauchly's test of sphericity was statistically significant for the LFA group, $w(27) = 0.01, p = .031$. F -values corrected using Greenhouse-Geisser estimates ($\epsilon = .47$) are reported. The covariate, chronological age, was statistically non-significant, $F(3.29, 39.44) = 0.90, p = .512$, partial $\eta^2 = .070$. Similarly, there was no statistically significant effect of true object location on mean absolute error response, $F(3.29, 39.44) = 1.34, p = .242$, partial $\eta^2 = .101$.

Mauchly's test of sphericity was statistically significant for the HFA group, $w(27) = 0.03, p < .001$. Corrected F -values using Greenhouse-Geisser estimates ($\epsilon = .51$) are reported. The covariate, chronological age, was not statistically significant, $F(3.55, 81.56) = 1.20, p = .309$, partial $\eta^2 = .049$. True object location also did not have a statistically significant effect on mean absolute error response, $F(3.55, 81.56) = 2.24, p = .079$, partial $\eta^2 = .089$.

For the MR group, Mauchly's test of sphericity was significant, $w(27) = 0.006, p = .010$. Corrected F -values using Greenhouse-Geisser estimates ($\epsilon = .48$) are reported. Chronological age, the covariate, did not significantly relate to mean absolute error response, $F(3.35, 40.24) = 0.34, p = .818$, partial $\eta^2 = .028$. There was also no statistically significant effect of true object location on mean absolute error response for participants in the MR group, $F(3.35, 40.24) = 0.23, p = .891$, partial $\eta^2 = .019$.

The mean error response for each group at each true object location is listed in Table 16. A MANCOVA was conducted to investigate between-group differences in mean error response for the various true object locations. The covariate for this analysis, chronological age, was

statistically non-significant for all the locations except location 2 ($F(1, 77) = 8.06, p = .006$, partial $\eta^2 = .095$) and location 7 ($F(1, 77) = 7.18, p = .009$, partial $\eta^2 = .085$). There were statistically significant between-group effects on error responses on the true object locations further from the centre of the cardboard (see Table 16). On those locations near to the centre of the space (P4 and P5) there was, however, not statistically significant between-group effect on error response.

Table 16.

SPC Group Mean Error Response

True Object Location	HFA <i>n</i> = 25	LFA <i>n</i> = 14	AS <i>n</i> = 12	TD <i>n</i> = 20	MR <i>n</i> = 13	<i>F</i>	<i>p</i>	Partial η^2
P1(89mm)	126.55 (124.93)	154.14 (98.89)	27.17 (26.67)	26.87 (33.18)	80.05 (110.09)	6.11	< .001**	.241
P2(178mm)	67.89 (53.28)	123.31 (72.82)	36.64 (32.30)	21.20 (29.92)	57.05 (91.34)	9.23	< .001**	.324
P3(267mm)	73.64 (59.76)	125.40 (63.98)	28.33 (30.73)	41.28 (49.18)	115.40 (77.54)	4.96	.001**	.324
P4(356mm)	58.91 (36.95)	69.31 (57.74)	39.89 (24.60)	33.05 (28.30)	81.12 (64.24)	2.38	.058	.105
P5(445mm)	71.81 (69.38)	61.43 (60.15)	38.17 (31.50)	38.33 (32.54)	57.33 (47.19)	2.45	.052	.108
P6(534mm)	79.15 (54.14)	91.88 (69.22)	55.42 (38.34)	36.48 (25.07)	69.02 (69.74)	4.44	.003**	.187
P7(623mm)	139.87 (114.24)	163.69 (100.05)	58.86 (74.49)	24.85 (24.97)	65.14 (60.97)	10.76	< .001**	.357
P8(712mm)	116.87 (107.72)	175.38 (131.72)	47.28 (63.42)	29.60 (24.20)	76.17 (77.30)	9.02	< .001**	.319

Note. HFA = high-functioning autism; LFA = low-functioning autism; AS = Asperger's syndrome; TD = typically developing; MR = mentally retarded. All means and standard deviations (SD) are presented in millimetres. All test statistics are based on *df*(4, 77).

** *p* < .01, two-tailed.

An *a priori* planned contrast revealed that at location 1, participants in the TD group had statistically significantly smaller mean error responses than did participants in the HFA ($t(1, 77) = 3.40, p = .001$) and LFA ($t(1, 77) = 3.70, p < .001$) groups. Post-hoc Bonferroni's pairwise comparisons showed that participants in the AS group also performed significantly better than did participants in the HFA ($p = .016$) and LFA ($p = .007$) groups. At position 2, participants in the TD group performed statistically significantly better than did participants in the LFA ($t(1, 77) = 5.19, p < .001$) and MR ($t(1, 77) = 7.72, p = .008$) groups. Similarly, pairwise comparisons indicated that participants in the AS group also performed statistically significantly better than did participants in the LFA ($p < .001$) and MR ($p = .036$) groups. Additionally, participants in the HFA group also performed statistically significantly better than did participants in the LFA ($p = .002$) group on this location. At location 3, participants in the TD group performed statistically significantly better than participants in the LFA ($t(1, 77) = 2.91, p = .005$) and MR ($t(1, 77) = 2.16, p = .034$) groups. Additionally, post-hoc pairwise comparisons showed that participants in the AS group also had statistically significantly lower mean error responses than participants in the LFA ($p = .002$) and MR ($p = .021$) groups at this true object location.

At location 6, *a priori* planned comparisons showed that participants in the TD group performed statistically significantly better than participants in the LFA ($t(1, 77) = -3.36, p = .001$) group. Post-hoc pairwise comparisons showed that participants in the AS group also performed statistically significantly better than participants in the LFA group ($p = .004$). At object location 7, *a priori* planned, simple contrasts showed that participants in the TD group performed statistically significantly better than those in the HFA ($t(1, 77) = -4.76, p < .001$), LFA ($t(1, 77) = -5.31, p < .001$), and MR ($t(1, 77) = -2.47, p = .016$) groups. Similarly for this location, Bonferroni's pairwise comparisons also revealed that participants in the AS group performed significantly better than participants in the HFA ($p = .004$) and LFA ($p = .001$) groups. On location 8, participants in the TD group performed statistically significantly better than participants in the HFA ($t(1, 77) = -3.74, p < .001$), LFA ($t(1, 77) = -5.38, p < .001$), and MR ($t(1, 77) = -2.14, p = .036$) groups. Participants in the AS group also performed significantly better than participants in the LFA group ($p = .001$) at this location.

Summary of Results on the SPC. On the SPC task, participants in the TD, AS, and MR groups replaced the object systematically towards the true object location. Those in the HFA and LFA groups did not. This suggests that these participants may have been placing the

object at random locations on the cardboard. Thus, any further results should be interpreted with caution. The above-reported results suggest that all of the participants showed a consistent level of bias across locations on the cardboard. In terms of the differences between the groups on this measure, there were statistically significant between-group effects at locations one, two, three, six, seven, and eight. Although the AS group performed equivalently to TD controls, the HFA, LFA, and MR participants performed significantly more poorly than those in the TD group at some of these locations. These statistically significant differences at all of the locations except those in the centre of the cardboard (P4 and P5) are expected if allocentric spatial processing is impaired. This is because those individuals who cannot encode spatial information allocentrically tend to find it more difficult to remember positions further from the centre of the continuous space on the SPC correctly (Pertini, 2004).

NBMT-CV Object Familiarisation

The covariate, chronological age, was statistically significantly related to the number of objects correctly recalled in the object familiarization stage of the NBMT-CV, $F(1, 80) = 4.99, p = .028$, partial $\eta^2 = .059$. After chronological age had been controlled, a one-way ANOVA still detected a statistically significant between-groups effect on the number of objects participants recalled after a 1-minute delay on the object familiarisation component of the NBMT-CV (see Table 17). Specifically, participants in the TD group remembered significantly more objects than did participants in the LFA ($p < .001$) and MR ($p < .001$) groups. Participants in the LFA also performed statistically significantly more poorly than did participants in the HFA ($p < .001$) and AS ($p < .001$) groups.

FBMT Total

There was a significant relationship between the covariates for this analysis (viz., age and object familiarisation) and performance on the FBMT, $F(1, 79) = 5.19, p = .025$, partial $\eta^2 = .062$ and $F(1, 79) = 17.18, p < .001$, partial $\eta^2 = .179$, respectively. Once these covariates had been controlled, however, a one-way ANOVA still detected a statistically significant between-groups effect on FBMT performance (see Table 17). *A priori* planned contrasts revealed that participants in the TD group performed statistically significantly better than participants in the HFA ($t(1, 79) = -2.00, p = .048$) and LFA ($t(1, 79) = -5.79, p < .001$) groups. Participants AS ($t(1, 79) = 6.51, p < .001$), HFA ($t(1, 79) = 4.86, p < .001$), and MR

($t(1, 79) = 5.32, p < .001$) groups also performed statistically significantly better than participants in the LFA group.

NBMT-CV Total

The covariate, chronological age, had no statistically significant effect on this outcome variable, $F(1, 44) = 0.15, p = .698$, partial $\eta^2 = .003$. The second covariate, number of objects recall in the object familiarisation stage, was, however, significantly related to this outcome variable, $F(1, 44) = 6.36, p = .015$, partial $\eta^2 = .126$. Even after this statistically significant covariate was controlled, a one-way ANOVA still detected a statistically significant between-groups effect on performance on this measure (see Table 18). *A priori* simple planned contrasts revealed that participants in the HFA group performed statistically significantly more poorly than participants in the TD group ($t(1, 40) = -4.54, p < .001$).

NBMT-CV Working Object Recall

The covariate, chronological age, did not significantly relate to the number of working objects participants were able to recall, $F(1, 44) = 0.57, p = .454$, partial $\eta^2 = .013$. The second covariate, the number of objects recalled in the object familiarisation stage, did, however, have a statistically significant effect on NBMT-CV Working Object performance, $F(1, 44) = 10.01, p = .003$, partial $\eta^2 = .185$. Even after this latter covariate was controlled, a one-way ANOVA still detected a statistically significant between-group effect on performance on this outcome variable (see Table 18). *A priori* planned comparisons revealed that participants in the TD group recalled statistically significantly more working objects than did participants in the HFA group ($t(1, 40) = -3.62, p < .001$).

Table 17.

Group Differences on NBMT-CV Object Familiarisation and FBMT Total

Variable	HFA <i>n</i> = 24	LFA <i>n</i> = 16	AS <i>n</i> = 13	TD <i>n</i> = 20	MR <i>n</i> = 13	<i>F</i>	<i>df</i>	<i>p</i>	Partial η^2
Object Familiarisation	5.08 (2.06)	2.13 (1.63)	4.62 (1.85)	6.05 (1.10)	3.77 (1.74)	4.99	4, 80	<.001**	.422
FBMT Total	19.67 (6.38)	8.19 (6.25)	22.46 (3.60)	23.65 (0.99)	19.85 (5.49)	13.14	4, 79	<.001**	.399

Note. HFA = high-functioning autism; LFA = low-functioning autism; AS = Asperger's syndrome; TD = typically developing; MR = mentally retarded.

Means are presented with standard deviation in parentheses.

***p* < .001, two-tailed.

Table 18.

Group Differences on NBMT-CV Outcome Variables

	HFA <i>n</i> = 18	AS <i>n</i> = 11	TD <i>n</i> = 20	<i>F</i>	<i>p</i>	Partial η^2
NBMT Total	35.33 (10.16)	49.36 (7.65)	55.40 (4.99)	35.12	<.001**	.615
NBMT Working Object Recall	5.00 (1.78)	6.09 (1.58)	7.05 (1.05)	10.55	<.001**	.324
NBMT Working Location Recall	5.06 (1.43)	6.09 (1.64)	6.85 (1.23)	3.15	.051	.104

Note. HFA = high-functioning autism; LFA = low-functioning autism; AS = Asperger's syndrome; TD = typically developing; MR = mentally retarded. Means are presented with standard deviation in parentheses. All test statistics are based on *df*(2, 44).

***p* < .001, two-tailed.

Table 19.

Group Differences on CG Arena Variables of Allocentric Spatial Ability

Variable	HFA <i>n</i> = 22	LFA <i>n</i> = 16	AS <i>n</i> = 12	TD <i>n</i> = 20	MR <i>n</i> = 20	<i>F</i>	<i>df</i>	<i>p</i>	Partial η^2
Number of times target found	4.55 (0.67)	4.00 (0.73)	4.17 (0.83)	4.65 (0.67)	4.67 (0.49)	2.80	4, 76	.032*	.129
Dwell time	32.01 (20.29)	28.55 (18.21)	56.37 (26.62)	57.02 (25.94)	29.21 (16.43)	8.27	4, 76	<.001**	.303
ART Score	23.50 (4.71)	24.50 (4.58)	16.75 (6.30)	16.20 (8.29)	22.58 (5.68)	7.29	4, 76	<.001**	.277
Deviation from Optimal Path Length	292.47 (165.36)	361.92 (137.91)	181.49 (85.88)	192.06 (122.38)	297.14 (125.46)	4.66	4, 77	.002*	.195
Trial 2	314.10 (253.30)	344.91 (225.64)	136.22 (139.78)	262.06 (262.19)	217.44 (214.05)				
Trial 3	265.24 (220.90)	437.83 (216.09)	170.40 (142.44)	194.66 (176.96)	303.75 (234.18)				
Trial 4	297.31 (249.47)	408.13 (233.76)	173.52 (132.86)	147.25 (163.11)	320.51 (215.83)				
Trial 5	297.31 (248.47)	356.83 (232.47)	245.83 (195.05)	189.29 (193.24)	346.84 (263.75)				

Note. HFA = high-functioning autism; LFA = low-functioning autism; AS = Asperger's syndrome; TD = typically developing; MR = mentally retarded.
Means are presented with standard deviations in parenthesis.

p* < .05, two-tailed. *p* < .001, two-tailed.

CG Arena Number of Times Target Found, Dwell Time, and ART Score

A MANCOVA showed that, the covariate, chronological age, was not statistically significantly related to performance on any of these outcome variables: Number of times target found, $F(1, 76) = 0.11, p = .741$, partial $\eta^2 = .001$; dwell time, $F(1, 76) = 3.45, p = .067$, partial $\eta^2 = .043$; ART Score, $F(1, 76) = 1.28, p = .261$, partial $\eta^2 = .017$. As displayed in Table 19, further results from the MANOVA showed that there were statistically significant between-groups effects on performance on all these outcome variables. *A priori* planned contrasts revealed that participants in the TD group found the target on more trials than did participants the LFA group ($t(1, 77) = 2.83, p = .006$). With regard to the dwell time, participants in the TD group spent a statistically significantly greater percentage of time searching for the target in the correct (NW) quadrant of the CG Arena than participants in the HFA ($t(1, 76) = -3.44, p < .001$), LFA ($t(1, 76) = -3.97, p < .001$), and MR ($t(1, 76) = -3.84, p < .001$) groups. Bonferroni's post-hoc multiple comparisons indicated that participants in the AS group also performed statistically significantly better on this outcome variable than participants in the HFA ($p = .007$), LFA ($p = .003$), and MR ($p = .006$) groups. Similarly, participants in the TD group performed statistically significantly better on the ART than participants in the HFA ($p < .001$), LFA ($p < .001$), and MR ($p = .003$) groups. Post-hoc pairwise comparisons also revealed that participants in the AS group also performed statistically significantly better than participants in the HFA ($p = .016$) and LFA ($p = .007$) groups on the ART.

CG Arena Deviation from Optimal Path Length

Figure 10 illustrates each group's mean deviation from the optimal path length on each of the CG Arena invisible trials. A repeated measures ANCOVA with age as the covariate, trial as the repeated measure, and group as the between subjects factor revealed no statistically significant relationship between the covariate, chronological age, and deviation from optimal path length, $F(3, 231) = 0.60, p = .618$, partial $\eta^2 = .008$. Also, deviation from optimal path length did not significantly vary depending on trial, $F(3, 231) = 0.55, p = .647$, partial $\eta^2 = .007$. In addition, the deviation from optimal path length x group interaction was statistically non-significant, $F(12, 231) = 1.36, p = .186$, partial $\eta^2 = .066$. Also, the covariate did not significantly relate to between-group performance on this variable, $F(1, 77) = 0.52, p = .472$, partial $\eta^2 = .007$. As Table 19 shows, there was, however, a significant main effect of group on this outcome variable.

A priori planned contrasts revealed that participants in the TD group were able to reach the invisible target using a path length significantly closer to the optimal path length than were participants in the HFA and LFA groups ($t(1, 77) = 2.48, p = .020$ and $t(1, 77) = 2.16, p = .034$, respectively). Post-hoc pairwise comparisons indicated that participants in the AS group also performed significantly better than participants in the LFA group ($p = .009$).

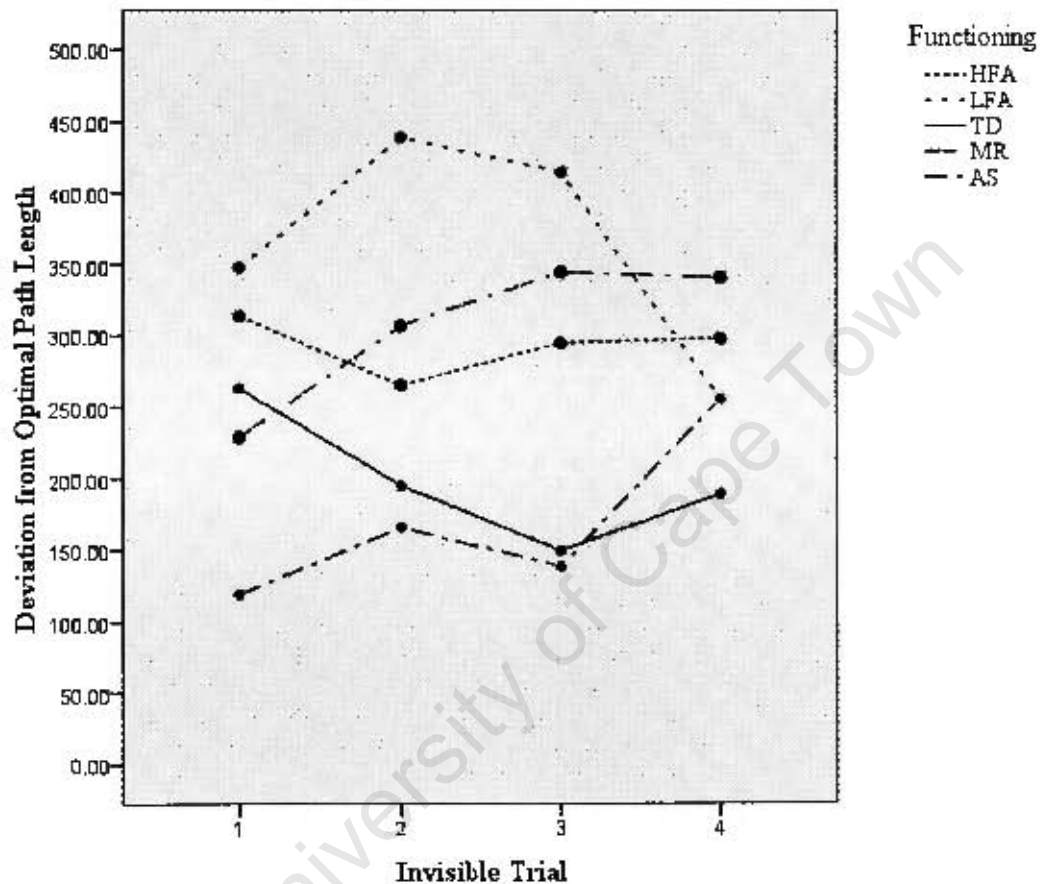


Figure 10. Mean group deviation from optimal path length across CG Arena invisible trials

The Effect of PIQ on Measures of Allocentric Spatial Ability

As Table 20 indicates, the linear regression analysis of the effect of PIQ on differences in allocentric spatial ability between the HFA, AS, and TD groups, PIQ accounted for a statistically significant amount of the variance in scores on all of the outcome variables of allocentric spatial ability used in this study except the SPC task. This suggests that intellectual functioning

influences allocentric spatial ability and that any statistically significant difference between these groups in allocentric spatial ability should be interpreted with caution.

Table 20.

The Effect of PIQ on Allocentric Spatial Ability for HFA, AS, and TD Groups

Test/ Outcome Variable	SE	β	R^2	F	df	p
SPC Mean Error	.263	.202	.041	2.09	1, 49	.154
Object Familiarisation	.130	.313	.098	4.88	1, 45	.032*
FBMT	.364	.380	.145	7.61	1, 45	.008*
NBMT-CV	.096	.548	.300	21.48	1, 50	<.001**
NBMT-CV Working Object Recall	.016	.380	.128	8.46	1, 50	.005*
CG Arena Dwell time	2.31	.365	.133	6.59	1, 43	.014*
CG Arena ART Score	.616	-.311	.097	4.60	1, 43	.038*
CG Arena Deviation from Optimal Path Length	14.25	-.106	.011	0.50	1, 44	.485

* $p < .05$. ** $p < .001$.

Summary of Results of Allocentric Spatial Ability

As expected, participants in the HFA and LFA groups performed significantly more poorly than participants in the TD group on all measures of allocentric spatial ability. Unexpectedly, however, there were no statistically significant between-group effects between participants in the PIQ-matched TD and AS groups. Consequently, allocentric spatial processing appears intact in children with AS. Moreover, participants in the LFA group performed statistically equivalently to participants in the MR group on all allocentric outcome variables except the FBMT: On that outcome variable, participants in the LFA group performed significantly more poorly than PIQ-matched MR controls. That result suggests deficient allocentric spatial ability in LFA individuals compared to non-ASD controls of similar IQ on that outcome variable.

For participants in the HFA group, PIQ accounted for a statistically significant amount of the variance on all measures of allocentric spatial ability except SPC error and CG Arena deviation from optimal path length. Consequently, the HFA group's poor performance on these outcome variables is confounded by PIQ. On the SPC and CG Arena deviation from optimal path length,

however, PIQ did not account for a statistically significant amount of the variance in scores between participants in the HFA, AS, and TD groups. Thus, one can infer that according to these outcome variables, participants in the HFA group showed deficient allocentric spatial ability regardless of their lower level of intellectual functioning.

Spatial Working Memory

NBMT-CV Working Location Recall

As this outcome variable is a component of the NBMT-CV, the same procedure of comparing only the scores of those participants who were able to complete the preliminary FBM and progress to the NBMT-CV were analysed. The results for this outcome variable are presented in Table 18 with the other NBMT-CV outcome variables. An ANCOVA of working location recall on the NBMT-CV showed that the covariate chronological age was not statistically significantly related to the number of working locations recalled on the NBMT-CV, $F(1, 54) = 0.38, p = .541$, partial $\eta^2 = .007$. The other covariate, number of objects recalled on the object familiarisation stage of the NBMT-CV was, however, statistically significant, $F(1, 54) = 5.19, p = .027$, partial $\eta^2 = .088$. The between-group effect on NBMT-CV working location recall was not statistically significant (see Table 18).

Summary of Results of Spatial Working Memory

According to these results, both AS and HFA children have intact spatial working memory compared to TD controls.

DISCUSSION

The frameworks of WCC (Prior & Ozonoff, 1998) and EF dysfunction (Frith, 1989) are two of the most prominent theories of ASD cognition in contemporary neuropsychological literature. Each of these theoretical frameworks claims to identify a core cognitive feature underlying the diverse behavioural permutations within the autism spectrum. As such, the predictions made by the theories should (a) be borne out consistently, regardless of which cognitive measures are used, and (b) consistent with cognitive and behavioural profiles of all individuals with ASD (Edgin & Pennington, 2005; Pennington, 2002). Although some empirical evidence substantiates these theories (see Hill, 2004; Kenworthy Yerys, Anthony, & Wallace, 2008; Ropar & Mitchell, 2001, for reviews), a number of recent studies have yielded contradictory results (see, e.g., Edgin

& Pennington, 2005; Lopez & Leekam, 2003). Similarly, the outcomes of the present research challenge both theories: Although this study provides partial support for the EF dysfunction theoretical framework in ASD, it did not confirm the predictions of visuo-spatial strength in ASD made by the theory of WCC.

In terms of visuo-spatial perception and spatial cognition, no visuo-spatial and no marked allocentric spatial deficits were found in this study. Instead, both specific visuo-spatial and broader allocentric spatial processes appear intact in ASD when intellectual ability is controlled. This contradicts the assumption that clinical and anecdotal reports of visuo-spatial skill in ASD indicates strengths in broader areas of spatial cognition (Caron et al., 2004; Edgin & Pennington, 2005). In other empirical studies, some authors have posited that ASD individuals show poor allocentric ability (i.e., object-to-object spatial deficits), while favouring egocentric spatial strategies (i.e., self-to-object approaches; Pertini, 2004). Intact allocentric spatial processing is, however, required for adequate overall spatial performance (Roche et al., 2005). In the present research, an allocentric processing deficit was found in HFA and LFA participants when compared to TD controls not matched by IQ. This same deficit was not, however, similarly replicated when these participants were compared to IQ-matched controls. The LFA participants performed equally in comparison to IQ-matched MR controls on most measures of allocentric ability. Similarly, there were no significant differences between participants in the AS group and those in the IQ-matched TD group. These results contradict some other empirical evidence. They are, however, much more plausible than those findings because intact overall spatial cognition in some ASD populations is only feasible if allocentric processing is also intact in some ASD individuals (Caron et al., 2004).

Executive Dysfunction

Recent research challenges the theoretical framework of EF dysfunction in ASD (Edgin & Pennington, 2005; Goldberg et al., 2005; Griffith, et al., 1999; Minshew, Goldstein, Muenz, & Payton, 1992; Minshew, Goldstein, & Seigel, 1997; Ozonoff, 1995; Pennington et al., 1997; Russell, et al., 1999). Some authors argue that conflicting evidence in research on EF in ASD is due to the over-simplification of the construct 'EF' itself by proponents of the EF dysfunction theory. In addition, the use of multi-component measures of EF in ASD research confounds

which factors of this broad cognitive domain are under investigation (Russo et al., 2007). It is possible that there is a pattern of impaired and intact EFs in ASD. Most research does not, however, divide complex EF tasks into their distinctive elements (Miyake et al., 2000; Russo et al., 2007). In this study, however, specific EFs and measures thereof were categorised according to V. Anderson et al.'s (2001) executive framework. Dividing these executive factors by domain, (those of attentional control, goal-setting, and cognitive flexibility) served to investigate results contrary to the theory of EF dysfunction in ASD further. In addition, it examined whether conflicting results across studies of EF in the field might be attributable to certain spared EF processes in ASD.

V. Anderson et al.'s (2001) model, used in the present research, is a valid system for grouping EF measures employed with children and adolescents. Most other studies of EF dysfunction in ASD fail to follow a specified model of EF (Kenworthy et al., 2008). This is surprising as, at present, EF is widely believed to be made up of distinct processes and not a merely singular construct (Miyake et al., 2000). Various authors have proposed that the construct of EF consists of concept formation, reasoning, and cognitive flexibility (Piguet et al., 2002), the purposeful, coordinated, and self-reflexive organisation of behaviour (Elliot, 2003), and task analysis, strategy control, and strategy monitoring (Borkowsky & Burke, 1996), among many others. Reviews on executive dysfunction in ASD have categorised measures used and results found in the literature according to the following domains: mental flexibility, inhibition, planning, generativity, working memory, or multiple EFs (Hill, 2004; Kenworthy, et al., 2008). Rarely, however, do individual studies attempt to define which specific domains are being measured or divide complex tasks (such as the WCST) into their constituent scores of separable EFs (e.g. perseverative errors as a measure of perseverance and number of categories completed as an indication of attention capacity). Moreover, there is no consensus on which executive model to follow in ASD research (Kenworthy et al., 2008). The use of a sound model of EF, such as V. Anderson et al.'s (2001), in the current research organises the complex neuropsychological construct of EF into the domains attentional control, goal-setting, and attentional control to more precisely investigate the nature of EF dysfunction in ASD.

The current research employed the WCST⁶⁴ failure to maintain set score as a measure of attentional control and found no significant differences between groups. This result suggests that at least one domain of EF (that measuring the ability to attend to presented stimuli in appropriate fashion and to process information efficiently) is intact across the autism spectrum. This conclusion is not, however, easily comparable to past studies on EF in ASD because of the above-mentioned disagreement in the neuropsychological literature on the precise definition of EF and its component processes (Jurado & Rosselli, 2007; Russo et al., 2007).

In addition, some might argue, however, that to infer that this result indicates intact attentional control in ASD is premature. This is because only one measure of attentional control was employed in this study. The finding would be better substantiated by using multiple measures of attentional control. In addition, this outcome variable, WCST⁶⁴ failure to maintain set, is not conclusively correlated to V. Anderson et al.'s (2001) domain, attentional control. Research such as Miyake et al.'s (2000) study employing factor analysis reveals that tasks such as the WCST⁶⁴ are most correlated with shifting which would fall under V. Anderson et al.'s (2001) domain, cognitive flexibility. They do not, however, take into account the complexity of EF tasks (Russo et al., 2008). Most tasks of EF derive several separable scores (e.g. the WCST⁶⁴ that yields nine different scores). In the case of the WCST⁶⁴, however, is it common for researchers to only examine perseverative errors and to disregard the numerous other scores obtained even though studies have shown them to be measures of correlated but separable aspects of EF (Hill, 2004). Indeed, Miyake et al.'s (2000) factor analysis only included the WCST⁶⁴ score perseverative errors. Further research is required to determine how well the tasks used in this study, including each outcome variable derived from single measures such as WCST⁶⁴ failure to maintain set, as well as other tasks that are widely used in autism research and their distinct scores, correlate to each of the executive domains in V. Anderson et al.'s (2001) model.

Thus, although future empirical enquiry is still needed to corroborate this finding, attentional control appears to be an executive domain not affected by ASD according to the present study. There were, however, statistically significant differences between ASD and non-ASD participants in other EF domains investigated. For instance, HFA and LFA children were impaired, compared to TD participants, on measures of cognitive flexibility and goal setting.

This finding replicates those from previous research (see Edgin and Pennington, 2005; Hill & Frith, 2003; Pennington & Ozonoff, 1996, for reviews).

In contrast, however, when compared to IQ-matched MR controls, the LFA participants in this study were not deficient in cognitive flexibility (i.e. cognitive control, complex working memory, and inhibition) according to any of the measures used. Similarly, participants also performed equally to age- and IQ-matched controls in planning, problem solving, and organisation as factors in the goal-setting domain. In this research, therefore, LFA participants did perform more poorly on measures of cognitive flexibility and goal setting than TD controls. When compared to an IQ-matched control group, however, to determine the specificity of these deficits to ASD, no differences were discovered. This outcome disconfirms predictions made by the theory of EF dysfunction. By that theoretical model, all individuals with ASD should have executive deficits compared to non-ASD controls (Ozonoff, Pennington, & Rogers, 1991; Russell, 1997).

Similarly, participants in the AS group in this study displayed intact EF compared to IQ-matched TD controls on all measures of cognitive flexibility and goal setting. This replicates other studies of AS individuals that fail to find EF deficits either at all or on certain measures or specific facets of EF (Baron-Cohen, 2004; Manjiviona & Prior, 1999). The present research supports this finding and disconfirms predictions made by the theory of EF dysfunction in ASD.

On one measure of cognitive flexibility, WCST⁶⁴ perseverative errors, this non-significant difference between the LFA and MR and the AS and TD participants in this study is particularly surprising. This is because this result is inconsistent with much past evidence of deficits on the perseverative errors score of the WCST⁶⁴ compared to non-ASD controls (see Edgin and Pennington, 2005; Hill & Frith, 2003; and Pennington & Ozonoff, 1996, for reviews). Some previous investigations have, however, yielded the same result of intact performance on this task (Edgin & Pennington, 2005; Minshew et al., 1992; Russell, et al., 1999; Schneider & Asarnow, 1987). Thus, there is inconsistent support for the cognitive inflexibility in ASD that is predicted by the theory of EF dysfunction in the literature.

Although the above-mentioned results contradict the theory of EF dysfunction, some support was given for the EF dysfunction theoretical framework by this study. Specifically, for the most part, participants in the HFA group performed significantly more poorly than TD and AS participants without the confounding of IQ. Even though participants in the HFA group had significantly lower IQs than those in the TD and AS groups, on most of the EF outcome variables used here regression analyses showed that poor performance by this group was comparable to that of participants in the AS and TD groups and was not influenced by intelligence. Consequently, one can infer that HFA children display EF deficits compared to TD controls even once IQ has been controlled. This result replicates previous studies in the field that provide support for the theoretical framework of EF dysfunction (see Edgin and Pennington, 2005; Hill & Frith, 2003; Pennington & Ozonoff, 1996 for reviews).

Moreover, with regard to comparisons between the HFA and AS participants, one can similarly infer that the HFA participants performed significantly more poorly than AS participants on the majority of outcome variable of cognitive flexibility and goal setting regardless of IQ. This replicates other recent research (Baron-Cohen, 2004). In addition, there is much debate over the diagnostics of AS and HFA (Manjiviona & Prior, 1999). Some authors argue that they are distinctly separable disorders. Yet, others assert that the underlying cognitive profiles of AS and HFA are the same (Hill & Frith, 2003). This present research provides evidence to the contrary, supporting the notion that AS and HFA are, at least in terms of executive ability, separable disorders.

In terms of all comparisons made between HFA and AS and TD participants, it is important to note, however, that this study cannot draw accurate inferences on the HFA participants' performance on two measures (ToL Rule Violations, a measure of cognitive flexibility, and WCST⁶⁴ Categories Completed, a measure of goal setting). This is because on these outcome variables IQ accounted for a statistically significant amount of the variance in scores. Forthcoming research should match the HFA group by IQ to a non-ASD control group to investigate differences on these outcome variables further.

Even so, the findings of this research largely contradict the theory of EF dysfunction in ASD. Such results suggest that the theory would benefit from refinement. Although reviews of the literature report mixed results on which specific EF processes are intact and which may be deficient, evidence for an overarching EF deficit in ASD is increasingly regarded as weak (Happé & Frith, 2006; Pennington & Ozonoff, 1996; Kenworthy et al., 2008). The EF dysfunction theory is therefore likely to benefit from definitions of 'executive function' that are more specific, and that rest on empirically derived sets of component processes (Edgin & Pennington, 2005; Miyake et al., 2000; Miyake et al., 2001; Stuss & Alexander, 2000; V. Anderson et al., 2001). Kenworthy et al. (2008) suggest that difficulties in EF measurement should be addressed by the creation of EF batteries that tap multiple sub domains of EF but that are easily separable into distinct factors of EF according to a sound and agreed theoretical model of EF. This notion is in line with the aims of the present research, which attempted to distinguish between specific intact and deficient EFs. Future research should continue to encourage the assessment of different domains of EF.

In corollary to further specification of which component EFs the theory of EF dysfunction alludes to, further investigation is also necessary to define more clearly which tasks and component scores of multi-factor measures of EF are most correlated to each executive domain (Hill, 2004). The finding of this research that abnormal executive functioning may not include the domain of attentional control challenges the theoretical framework of EF dysfunction: The executive deficits in ASD cognition that are predicted by the theory are clearly not replicable across all domains of EF. This finding is in line with other recent research that, for example, implicates deficits in planning but not in inhibition or working memory (Griffith, et al., 1999; Kenworthy et al., 2008; Ozonoff & Strayer, 2001).

Another downfall of the theoretical framework of EF dysfunction that has been highlighted by the current research is that EF dysfunction does not appear universal in ASD. Mostly, ASD researchers compare children with ASD to TD children. Where this includes IQ matching, this is usually between HFA and TD participants. The choice of comparison groups in ASD research is vital to the types of conclusions that can be drawn. The findings of the bulk of ASD research, which examines ASD performance in relation to TD controls, inform us about the differences in

ASD from the norm. Contrary to what proponents of the EF theory purport, this does not necessarily indicate the uniqueness of findings to ASD as opposed to all atypical populations (Russo et al., 2007). The fact that in this study results varied according to ASD population (i.e. HFA, LFA, or AS) suggests that some of the variability of results in ASD research on EF is indeed attributable to differences across the autism spectrum.

This outcome replicates previous studies on EF in ASD, which also failed to find significant differences in performance between IQ-matched ASD participants and moderately learning disabled or developmentally delayed controls (Bennetto, Pennington, & Rogers, 1996; Griffith et al., 1999; McEvoy, Rogers, & Pennington, 1993; Russell, Jarrold, & Henry, 1996; Yerys, Hepburn, Pennington, & Rogers, 2007). Thus, the EF dysfunction theory does not appear consistent across the autism spectrum.

One possible explanation for this diversity is that some research indicates that EF is correlated to IQ (Carpenter, Just, & Shell, 1990; Salthouse, Atkinson, & Berish, 2003; Salthouse, Fristoe, McGunthry, & Hambrick, 1998) and that some separable functions (e.g., cognitive flexibility) are more highly correlated with general intellectual functioning than others (e.g., goal setting; Friedman et al., 2006). If this is the case, then it is no surprise that lower-functioning individuals with ASD would display EF deficits when compared to higher IQ controls. In this study, however, the effect of intellectual ability was controlled by comparing LFA children to IQ-matched participants (the MR group). The lack of statistically significant differences in performance between participants in these two groups suggests that EF deficits documented in ASD may not be a function of the disorder itself. On the contrary, they may in fact be related to learning delay and developmental disorders in general (Russo et al., 2008). Moreover, this conclusion indicates that the theory of EF dysfunction is not universal to all individuals with ASD. Future research is, however, necessary to replicate this result as so few investigations thus far have included LFA participants.

In summary, proponents of the EF dysfunction theory of ASD cognition propose a core cognitive executive deficit that is consistent across the autism spectrum (Ozonoff, et al., 1991; Russell, 1997). Findings from the present research, however, refute this claim. For instance, for all

participants, the executive factor of attentional control was intact. Further, participants in the AS group did not display any EF deficits, whereas participants in the HFA group were relatively impaired on measures of cognitive flexibility and goal setting. Moreover, participants in the LFA group did not in general display any unique EF deficits when compared to IQ-matched, MR controls. Although these results stand in contrast to past evidence claiming a deficit in overall EF (but most often in set-shifting, which would fall under V. Anderson et al.'s (2001) cognitive flexibility domain), it replicates recent research which suggests that EF dysfunction is not as pervasive in ASD as was previously thought (Baron-Cohen, 2004; Edgin & Pennington, 2005). These findings bring into serious question the strength of the theory of EF dysfunction in ASD. They indicate that the theory is not consistent across measures or domains of EF. In addition, this research shows that there is variation in EF dysfunction across the ASD spectrum. Consequently, the theory appears inapplicable as an explanation of a core cognitive feature of ASD.

With regard to future research on executive function and dysfunction in ASD, a great deal more clarity is required of our understanding of EF, the tasks formulated to measure this broad and illusive construct, and the experimental conditions that make accurate inferences of executive ability possible. With specific regard to this latter point, some studies suggest that performance by ASD participants on measures of cognitive flexibility such as the WCST⁶⁴ may improve when extraneous demands on the task are minimized. For instance, a lesser amount of experimenter feedback given to ASD participants may help them to complete the task efficiently (Edgin & Pennington, 2005). This is also apparent in improved EF ability in ASD children when a computer as apposed to a human administers tasks (Ozonoff, 1995; Pascualvaca, Fantie, Papageorgiou, & Mirsky, 1998).

Visuo-Spatial Ability

Another theory that posits a singular, universal cognitive deficit in ASD is that of WCC (Frith, 1989). Research reports that individuals with ASD have superior visuo-spatial skill compared to non-ASD individuals (see Happe & Booth, 2008, for a review). The theory of executive dysfunction falters in its explanation of these relative visuo-spatial strengths documented in individuals with autism (Edgin & Pennington, 2005). The theoretical framework of WCC, however, predicts this enhanced ability. Proponents of the WCC theory propose a preference for

figural attention over global processing in ASD. They argue that this local bias manifests as visuo-spatial strengths in ASD cognition (Happé & Booth, 2008). The present research provided no support for this conjecture as, at best, visuo-spatial ability was only intact (and not superior) in ASD participants when compared to non-ASD controls. Moreover, the current results also suggest some variability in this processing style within the ASD population.

In this study, there were no statistically significant differences in scores on visuo-spatial measures between the IQ-matched AS and TD or LFA and MR groups on the CEFT, the ROCF 36-pt Copy, or the BD (i.e. all of the outcomes variables of visuo-spatial perception used). This result disconfirms predictions derived from the theory of WCC, and is inconsistent with past evidence for this theoretical framework (see Happé & Frith, 2006, for a comprehensive review). Other recent studies have, however, similarly brought these visuo-spatial strengths in ASD into question (see, e.g., Brian & Bryson, 1996; Catanzaro, 2005; Edgin & Pennington, 2005; Jolliffe & Baron-Cohen, 1997; Lopez & Leekam, 2003; Ozonoff, et al., 1994; Plaisted, et al., 1999; Rinehart et al., 2000; Ropar & Mitchell, 1999; Ropar & Mitchell, 2001; Schlooz et al., 2006). This outcome brings into question the applicability of the theory of WCC as an explanation of a cognitive processing style underlying the behavioural symptoms of ASD.

For WCC to be a core feature of ASD cognition, it must be proven universal to all ASD individuals, yet many studies of WCC in ASD only recruit HFA and AS participants (see Happé & Booth, 2008, for a review). Very few previous studies on WCC in ASD have included LFA participants. One rare investigation using LFA participants matched to non-ASD MR controls, however, provided partial support for the theory of WCC in this population (van Lang et al., 2006). In support of the findings of this study, van Lang et al.'s (2006) investigation also failed to find any differences between LFA and IQ-matched MR participants on the CEFT that requires disembedding and is widely used as a tool to explore WCC in ASD. Unlike the present research, however, which similarly failed to find a significant difference in performance between LFA and MR participants on the BD (i.e., a task also requiring detailed-focused processing), LFA participants in that study performed better on the same task than non-ASD, MR controls. This outcome is dissimilar to those of the present research.

Although, this result may be because Van Lang et al.'s (2006) research tested WCC in LFA and MR adolescents whereas the current research recruited mainly younger children. This may suggest that WCC becomes more pronounced with age in ASD. The divergence between these results is, however, more likely attributable to differences of measurement. Although both the present and van Lang et al.'s (2006) studies employed the BD as a measure of visuo-spatial skill, Van Lang et al. (2006) scored the subtest according to accuracy and speed. The group differences they found were in the speed with which the LFA participants completed the task compared to MR controls. Therefore, the LFA participants were significantly faster at completing each correct design than MR controls but did not necessarily complete more designs correctly than the MR control group. In the present study, BD score, which is a composite score that combines speed and accuracy, was used as an outcome variable in the present research. Future research should investigate whether superior BD performance is, in fact, in terms of speed of completion rather than accuracy. Clearly, if proponents of the theory of WCC are going to contend that WCC is universal to ASD, significantly more research on WCC with LFA participants needs to be conducted in order to resolve these and other questions.

The theory of WCC posits that a universal processing deficit in ASD manifests as a strength on tasks of visuo-spatial perception such as the CEFT that benefit from the ability to see past the gestalt of an image in order to attend to its minutiae (i.e., WCC; Happe & Booth, 2008). Consequently, merely intact performance by LFA and AS participants on this measure compared to IQ-matched MR and TD controls, suggests that some children with ASD are no more biased towards the local elements of a figure than non-ASD controls. Following this line of reasoning, Mottron et al. (1999) propose that a local processing bias may only become evident when children with ASD are faced with greater processing demands. Similarly, authors that fail to find a global processing deficit in ASD argue that this pattern of cognition might only appear at a representational level (Joliffe & Baron-Cohen, 2001).

Furthermore, the way in which the CEFT is scored may also determine whether one obtains data suggesting ASD participants exhibit strengths on this measure compared to non-ASD controls. There is some evidence for using the number of attempts needed to find the hidden shape, rather than the number of embedded figures correctly identified or the speed with which they are

discovered, as a more subtle measure of disembedding (de Jonge, et al., 2006). Future research should examine whether different variants of CEFT score tap into diverse neuro-cognitive processes.

Test of visuo-spatial perception such as the CEFT are not commonly considered highly influenced by intelligence (Lubinski, 2004). For HFA participants in this research, however, IQ exerted a substantial effect on their performance on both the CEFT and the ROCF 36-pt Copy compared to AS and TD participants. Moreover, the HFA participants BD scores were not analysed because the BD, as a subtest of the WASI, is inherently reliant on IQ. As such, no conclusive inferences on the visuo-spatial ability of this group can be drawn. This result may, however, suggest a correlation between perceptual processing and IQ that would benefit from further investigation. Indeed, some researchers suggest that visuo-spatial perception is highly correlated to spatial working memory and, consequently, to EF and intelligence (Miyake et al., 2001).

Many of the tasks used to indicate visuo-spatial superiority in ASD require elements of executive function to complete. For example, BD performance is often cited as an area of strength in ASD cognition (Happé & Booth, 2008). Yet, performance on this measure relies on the executive functioning elements of planning, goal-directed cognition, and, perhaps most importantly, working memory. One proposed explanation for the inconsistency of intact performance on visuo-spatial measures such as the BD in ASD even though they necessitate EF to complete, which is deficient in ASD according to the theory of EF dysfunction, is that there is no spatial working memory deficit in ASD cognition. Rather, the deficit may be limited to verbal working memory. Specifically, ASD individuals may be able to store spatial information in immediate memory long enough to be able to manipulate spatial stimuli efficiently (Edgin & Pennington, 2005). Indeed, although some recent research has described poor spatial working memory in HFA individuals (Landa & Goldberg, 2005; Williams, et al., 2006), other empirical evidence supports the view that it may be intact (see Edgin & Pennington, 2005; Griffith, et al., 1999; Ozonoff & Strayer, 2001). For example, Ozonoff & Strayer (2001) failed to find a spatial working memory deficit in HFA adolescents compared to TD participants on the Spatial N Back, Box Search, or Spatial Location Span tests. Similarly, Edgin & Pennington's (2005) research

using the CANTAB Spatial Working Memory Test, also failed to find a significant difference between ASD (AS and HFA) and TD participants.

Similarly, the current research replicated intact spatial working memory in AS and HFA participants (specifically, their performance on the NBMT-CV working location outcome variable was equal compared to TD controls). In this study BD performance was intact but not superior in the ASD participants whose scores on this measure were analysed (i.e. those in the LFA and AS groups). Similarly, attentional control was intact in all ASD participants and LFA and AS participants showed relatively intact performance in other executive domains. The sum total of this pattern of data might be that, in ASD, visuo-spatial ability is intact on measures requiring EF to complete because certain EF domains including spatial working memory are in fact also intact in ASD. This interpretation presents a much less ambiguous profile of ASD cognition than is proposed by either the EF dysfunction or WCC theoretical framework operating in isolation.

In summary, the findings of this research indicate that the theoretical framework of WCC may not be as complete an explanation of the multifaceted profile of visuo-spatial processing in ASD as is widely contended (Caron et al., 2004; Edgin & Pennington, 2005; Mitchell & Ropar, 2004). Specifically, the results of this study suggest that, at best, visuo-spatial ability is, compared to age- and IQ-matched controls, merely intact in ASD individuals. Hence, although visuo-spatial abilities may be one of the strengths in the cognitive profile of an ASD individual, this strength is only relative to other areas of cognition, which may be deficient.

Allocentric and Egocentric Spatial Ability

The conclusions discussed above contradict both the WCC and the EF dysfunction theoretical frameworks. They depict, however, a more consistent description of the cognitive profile of ASD, particularly in terms of how intact (or sometimes reportedly superior) spatial abilities documented in ASD are feasible. Superior general spatial cognition is often assumed based on relative visuo-spatial skill reported in ASD and described by the theory of WCC. As mentioned above, the WCC theory suggests that individuals with ASD are unable to attend to global forms. Instead, the WCC theory posits, individuals with ASD perceive the basic details or perceptual

elements of stimuli (Frith & Happe, 2006). This conjecture may arguably explain intact visual-spatial perception on tasks involving visual illusions and embedded figures. It does not, however, make clear how individuals with ASD are often superior at drawing, object assembly, and mental rotation. These skills, as well as broader spatial ability, require the perception and integration of both global and local spatial configurations (Edgin & Pennington, 2005). If, however, as the findings of the present research suggest, visuo-spatial perception in ASD is similar to that of IQ-matched controls, then adequate broad spatial functioning and navigation is explicable.

In addition to the ability to access both local and global spatial configurations, spatial navigation requires aspects of EF. Planning, organization, and the capacity to attend to, shift between, and integrate visual information are necessary for adequate spatial cognition. This research reports that EF dysfunction is not as pervasive in ASD with regard to both the specific functions affected and the population subgroups involved as is argued by proponents of the EF dysfunction theory. Consequently, intact spatial cognition in ASD is plausible even if it does require elements of EF to complete.

Broad spatial cognition, including spatial navigation, also requires allocentric spatial coding; past research suggests that individuals with ASD might have impaired abilities in this regard. ASD individuals are said to display extreme egocentric tendencies and to lack the ability to code information allocentrically (Frith & de Vignemont, 2005; Gillberg & Gillberg, 1989). The present findings, however, revealed that only the AS participants displayed intact allocentric spatial ability compared to TD participants. This finding in AS participants replicates Pertini's (2004) research findings. When compared to other developmentally delayed, MR children, however, the LFA group also showed comparable allocentric spatial ability. Surprisingly, IQ appeared to play a definitive role in performance on these tasks. For example, the HFA group performed worse than TD and AS participants in this study. The significant influence of IQ means, however, that this difference may have largely resulted from this effect.

On the SPC and CG Arena, however, mean error response and deviation from the optimal path length on experimental trials were not significantly affected by intellectual ability. This pattern of data suggests that on these outcome variables, HFA children have a lesser aptitude for

allocentric spatial coding than TD children, irrespective of IQ. In Edgin and Pennington's (2005) research, they found HFA and AS participants displayed intact but not superior performance on the CG Arena. They, however, only used the amount of time spent searching in the correct quadrant on the probe trial as the outcome variable of interest. Consequently, further research is required to investigate the influence of IQ on certain measures of spatial ability. In addition, as spatial navigational ability in ASD is particularly under researched (see Sigman, et al., 2006 for a review), future studies using a comprehensive measure of spatial navigation such as the CG Arena are needed to replicate these findings.

With regard to allocentric spatial processing, an ability required for intact spatial navigation, ASD participants were expected to perform significantly more poorly than non-ASD controls (Pertini, 2004). As mentioned above, unexpectedly, the AS and LFA participants performed equivalently to IQ-matched controls on allocentric measures. This suggests either that intellectual ability is highly correlated to allocentric coding ability or that there are features of AS and LFA that promote allocentric spatial processing. The HFA participants in this study performed more poorly than TD controls. IQ, however, played a significant role in this outcome on most measures of allocentric ability. In contrast, on other measures IQ did not affect the HFA participants' performance. Even so, on these tasks this group still performed more poorly than TD controls. This indicates that for HFA participants, the hypothesis that they are unable to process information allocentrically that was initially expected may be valid.

In terms of egocentric spatial ability, the hypothesis that ASD participants should perform as well as non-ASD controls was confirmed for participants in the AS and the LFA groups. This result replicates other research in the field (e.g. Pertini, 2004). It also confirms what leading authors theorise by drawing on the social idiosyncrasies in ASD (Frith & de Vignemont, 2005). In contrast, participants in the HFA group performed more poorly than those in the AS and TD groups. Similar to what was found with allocentric ability, however, the influence of IQ significantly affected between-group comparisons of egocentric coding ability in these three groups.

Methodological Constraints

The participants in this research were closely matched by sex and handedness. Given the difficulties in recruiting a large enough sample of ASD participants, however, complete matching on all demographic factors was not possible. In consequence, there were statistically significant between-group differences in home language, chronological age race, and IQ.

Even though the home language of the participants in the research differed significantly across groups, it should have no bearing on conclusions drawn. Each participant was taught in either English or in English and Afrikaans and was reported by his/her teacher as being able to understand/ speak English well enough to complete the test battery. Perhaps future research might, however, benefit from ensuring that all participants are home-language English speaking. This will, however, limit the recruitment pool from which participants can be drawn. In addition, doing so would limit the findings of the research to a small sub-sample of the South African population.

With regard to age, participants in the AS group were statistically significantly younger at the time of testing than participants in the other groups. This unanticipated age difference largely arose because AS participants were particularly difficult to recruit. Mostly, children with AS do not need highly specialised education due to their high range IQ and intact verbal ability; they thus attend mainstream or mild remedial schooling. Consequently, making contact with a large group of children with AS proved difficult. Unlike children diagnosed with either HFA or LFA, children with AS are often not required to attend special schooling as their symptoms are less pronounced and they do not need intensive remedial education. Children with AS are, therefore, not often congregated at one specialised school like those with HFA or LFA autism. To make up for this discrepancy in age of the sample of AS participants recruited, chronological age was entered as a covariate into all data analysis. Consequently, the between-groups age discrepancy should not influence the validity of this research. Future research should, however, attempt to recruit both a greater number of AS participants as well as a greater age range of AS participants perhaps by making contact with support groups and other bodies not necessarily affiliated to schools.

There were also statistically significant differences between the AS and other groups in race. Again, this is due to difficulties accessing AS participants for research. There is, however, no literature predicting that race has an effect on cognitive functioning in ASD. Consequently, this divergence should be of no consequence to the outcomes of the present research.

Of greater import than race to neuropsychological research is socio-economic status (McLoyd, 1998). SES was not included as a variable in this research, however, as many school principals felt parents would have been less likely to agree to participate in the research if asked to proffer personal or financial information. It can be assumed, however, that the children who participated in this research are likely to come from similar socio-economic backgrounds as they all attended similar schools that cater for middle-to-upper income families. Future research would, however, benefit from matching according to SES so that any ecological differences between groups of participants might be ruled out.

Participants in this research were matched as far as possible according to IQ. One of the aims of this research was to compare various groups of participants with ASD to non-ASD controls of matching IQ. Indeed, the LFA group were accurately matched to the MR group. Similarly, participants in the AS group had equivalent IQ scores to TD participants. The LFA and MR groups were included in the research to investigate a wider representation of IQ in ASD than is currently represented in the literature. Most ASD research employs HFA participants and compares performance on measures of cognition to TD children. Such research is most often able to match HFA participants to TD participants by IQ as the HFA participants recruited fall into the average range of intelligence. Yet, by definition in the literature, ASD individuals are said to be HFA if they present with an IQ of 70 and above. This criterion was used in the present research to distinguish between HFA and LFA participants. Surprisingly, however, in this research participants in the HFA group had significantly lower IQ scores than those in the TD group but significantly higher scores than those of participants in the MR group. Consequently, the HFA group could not be matched with any non-ASD group in this research. Lopez and Leekam (2003) also found that they could not accurately match HFA participants to TD controls by intelligence. As a result, those researchers included IQ as a covariate in all analyses used. Similarly, in this study, if significant differences in scores were discovered between the HFA,

AS, and TD groups, regression analysis were employed to determine whether for the HFA group IQ was a significant predictor of performance.

Ideally, of course, in this research the HFA should have been compared to an IQ-matched control group. The fact that it was not possible to do so even though the correct definition of HFA was utilised suggests that other research misrepresents HFA. If research is merely being conducted with HFA participants in the average range of IQ (i.e., scores of 90-110) then HFA is not being accurately investigated. This may explain some of the divergence in results in the field. Even though choosing HFA participants at the top of the IQ range may promote good experimental design, it detracts from the clinical significance of ASD research. Future research should recruit not only those HFA individuals who fall into the average IQ range but also those in the 70-90 IQ range. It should also, however, attempt to match these participants to non-ASD controls of equivalent intellectual ability.

Despite these methodological constraints, the present study adds to the rapidly increasing body of research that disconfirms predictions derived from the theoretical frameworks of EF dysfunction and WCC. Specifically, the current results question the applicability of either of these frameworks as descriptions of a single core cognitive feature underlying the positive symptoms of ASD. This is not to say that either of these theories is unfounded. Instead, they may benefit from refinement. The theory of EF dysfunction appears to require further distinction of the specific EFs that may be deficient in ASD. This is true given that EF is a broad construct that is not yet fully understood. Moreover, there are various measures of EF that themselves test divergent executive capabilities. With regard to the theory of WCC, not much support was provided by this research. The visuo-spatial peaks in ASD predicted by the theory of WCC are not always apparent and at times differ according to task. Consequently, this theoretical framework might also benefit from task specificity. That is, WCC might be present on some tasks but not on others and the theory needs to make clear to which specific measures it applies. In addition, visuo-spatial perception appears intact but not superior in ASD. Furthermore, strengths in broader areas of spatial cognition based on superior visuo-spatial functioning are not replicable. Perhaps most importantly, both above-mentioned theories fail to represent a consistent description of cognition for individuals across the autism spectrum. This study shows

that results found using one group of the ASD population cannot necessarily be extrapolated to all other ASD individuals, even those with autistic disorder but differing in intellectual ability, i.e. HFA and LFA children. Further research with a wider array of ASD participants with differing capabilities is vital to a more accurate understanding of ASD cognition.

University of Cape Town

REFERENCES

- American Psychiatric Association. (2000). *Diagnostic and statistical manual of mental disorders* (4th ed.). (Text Revision). Washington, DC: Author.
- Anderson, P., Anderson, V., & Garth, J. (2001). Assessment and development of organizational ability: the Rey Complex Figure Organisational Strategy Score (RCF-OSS). *The Clinical Neuropsychologist*, 15, 81-94.
- Anderson V. A., Anderson, P., Northam, E., Jacobs, R., & Catroppa, C. (2001). Development of executive functions through late childhood and adolescence in an Australian sample. *Developmental Neuropsychology*, 20, 385-406.
- Baddeley, A. D. (1986). *Working memory*. New York, NY: Oxford University Press.
- Baron-Cohen, S. (2004). Autism: research into causes and intervention. *Pediatric Rehabilitation*, 7, 73-78.
- Bennetto, L., Pennington, B. F., & Rogers, S. J. (1996). Intact and impaired memory functions in autism. *Child Development*, 67, 1816-1835.
- Bertone, A., Mottron, L., Jelenic, P., & Faubert, J. (2005). Enhanced and diminished visuo-spatial information processing in autism depends on stimulus complexity. *Brain*, 128, 2430-2441.
- Borkowsky, J. G., & Burke, J. E. (1996). Theories, models and measurements of executive functioning: An information processing perspective. In G. R. Lyon, & N. A. Krasnegor (Eds.). *Attention, memory and executive function*. Baltimore, USA: Paul H. Brookes.
- Bradshaw, J. L. (1989). *Hemispheric specialization and psychological function*. Chichester, UK: John Wiley & Sons.

- Brian, J. A., & Bryson, S. E. (1996). Disembedding performance and recognition memory in autism/PDD. *Journal of Child Psychology and Psychiatry*, 37, 865-872.
- Buchner, A., Erdfelder, E., & Faul, F. (1997). How to use G*Power [Computer software and manual]. Retrieved August 3, 2006, from http://www.pscho.uni-duesseldorf.de/aap/projects/gpower/how_to_use_gpower.html
- Caron, M. J., Mottron, L., Berthiaume, C., & Dawson, M. (2006). Cognitive mechanisms, specificity and neural underpinnings of visuospatial peaks in autism. *Brain*, 129, 1789-1802.
- Caron, M. J., Mottron, L., Rainville, C., & Chouinard, S. (2004). Do high functioning persons with autism present superior spatial abilities? *Neuropsychologia*, 42, 467-481.
- Carpenter, P. A., Just, M. A., & Shell, P. (1990). What one intelligence test measures: A theoretical account of the processing in the Raven Progressive Matrices Test. *Psychological Review*, 97, 404-431.
- Catanzaro, R. (2005). *Performance on the Rey-Osterrieth Complex Figure in high-functioning autism*. Unpublished doctoral thesis, University of Pennsylvania, United States of America.
- Cohen, J. (1977). *Statistical power analysis for the behavioural sciences* (Rev. ed.). New York, NY: Academic Press.
- Cohen, J. (1988). *Statistical power analysis for the behavioural sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.
- Culbertson, C. W., & Zillmer, E. A. (2001). *Tower of London Drexel University (ToL DX): Technical manual*. North Tonawanda, NY: Multi-Health Systems Inc.

- D'Andrea, E. A., & Spiers, M. V. (2005). The effect of familial sinistrality and academic experience on cognition in right-handed women. *Neuropsychology*, 19, 657-663.
- De Jonge, M. V., Kemner, C., de Haan, E. H., Coppens, J. E., van den Berg, T. J., & van Engeland, H. (2007). Visual information processing in high-functioning individuals with autism spectrum disorders and their parents. *Neuropsychology*, 21, 65-73.
- Duncan, J., Emslie, H., Williams, P., Johnson, R., & Freer, C. (1996). Intelligence and the frontal lobe: The organization of goal directed behaviour. *Cognitive Psychology*, 30, 257-303.
- Edgin, J. O. & Pennington, B. F. (2005). Spatial cognition in autism spectrum disorders: superior, impaired, or just intact? *Journal of Autism and Developmental Disorders*, 35, 729-745.
- Elliot, R. (2003). Executive functions and their disorders. *British Medical Bulletin*, 65, 49-59.
- Erdfelder, E., Faul, F., & Buchner, A. (1996). GPower: A general power analysis program. *Behaviour Research Methods, Instruments, & Computers*, 28, 1-11.
- Frith, U. (1989). *Autism: Explaining the enigma*. Oxford, U.K.: Blackwell Publishers.
- Frith, U. (1997). The neurocognitive basis of autism. *Trends in Cognitive Neuroscience*, 1, 73-77.
- Frith, U., & de Vignemont, F. (2005). Egocentrism, allocentrism, and Asperger syndrome. *Consciousness and Cognition*, 14, 719-738.
- Frith, U., & Happe, F. (1994). Autism: Beyond "theory of mind". *Cognition*, 50, 115-132.

- Gillberg, I. C., & Gilberg, C. (1989). Asperger Syndrome- Some epidemiological considerations: A research note. *Journal of Child Psychology and Psychiatry*, 30, 631-638.
- Goldberg, M. C., Mostofsky, S. H., Cutting, L. E., Mahone, E. M., Astor, B. C., et al. (2005). Subtle executive impairments in children with autism and ADHD. *Journal of Autism and Developmental Disorders*, 35, 379-293.
- Griffith, E. M., Pennington, B. F., Wehner, E. A., & Rogers, S. J. (1999). Executive functions in young children with autism. *Child Development*, 70, 817-832.
- Happe, F. G. (1999). Autism: Cognitive deficit or cognitive style? *Trends in Cognitive Neurosciences*, 3, 216-222.
- Happe, F. G. E., & Booth, R. D. L. (2008). The power of the positive: Revisiting weak coherence in autism spectrum disorders. *The Quarterly Journal of Experimental Psychology*, 61, 50-63.
- Happe, F., & Frith, U. (2006). The weak coherence account: detail-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders*, 36, 5-25.
- Hill, E. L., & Frith, U. (2003). Understanding autism: Insights from mind and brain. *Philosophical Transactions of the Royal Society of London*, 358, 281-289.
- Hill, E. L. (2004). Executive dysfunction in autism. *Trends in Cognitive Neurosciences*, 8, 26-32.
- Holdstock, J. S., Mayes, A. R., Cezayirli, E., Isaac, C. L., Aggleton, J. P., & Robert, N. (2000). A comparison of egocentric and allocentric spatial memory in a patient with selective hippocampal damage. *Neuropsychologia*, 38, 410-425.

- Joliffe, T. & Baron-Cohen, S. (1997). Are people with autism or Asperger's Syndrome faster than normal on the Embedded Figures Task? *Journal of Child Psychology and Psychiatry*, 24, 613-620.
- Jurado, M., & Rosselli, M. (2007). The elusive nature of executive functions: A review of our current understandings. *Neuropsychology*, 17, 213-233.
- Kabot, S., Masi, W., & Segal, M. (2003). Advances in the diagnosis and treatment of autism spectrum disorders. *Professional Psychology: Research Practice*, 34, 26-33.
- Kaland, N., Smith, L., & Mortensen, E. (2007). Response times of children and adolescents with Asperger's Syndrome on an 'advanced' test of theory of mind. *Journal of Autism and Developmental Disorders*, 37, 197-209.
- Kenworthy, L., Yerys, B. E., Anthony, L. G., & Wallace, G. L. (2008). Understanding executive control in Autism Spectrum Disorders in the lab and in the real world. *Neuropsychological Review*, 18, 320-338.
- Kongs, S. K., Thompson, L. L., Iverson, G. L., & Heaton, R. K. (2000). *WCST⁶⁴: Wisconsin Card Sorting Test-64 card version professional manual*. Odessa, FL: Psychological Assessment Resources.
- Landa, R., & Goldberg, M. C. (2005). Language, social, and executive functions in high-functioning autism: A continuum of performance. *Journal of Autism and Developmental Disorders*, 35, 557-573.
- Lezak, M. D. (1983). *Neuropsychological assessment* (2nd ed.). New York: Oxford University Press.
- Lopez, B., & Leekam, S. R. (2003). Do children with autism fail to process information in context? *Journal of Child Psychology and Psychiatry*, 44, 285-300.

- Lubinski, D. (2004). Introduction to the special section on cognitive abilities: 100 years after Spearman's (1904) "General Intelligence, Objectively Determined and Measured". *Journal of Personality and Social Psychology*, 86, 96-111.
- Manjiviona, J., & Prior, M. (1999). Neuropsychological profiles of children with Asperger's syndrome and autism. *Autism*, 3, 327-356.
- Marshall, J. C., & Fink, G. R. (2001). Spatial cognition: where we were and where we are. *NeuroImage*, 14, 52-57.
- McEvoy, R., Rogers, S. J., & Pennington, B. F. (1993). Executive function and social communication deficits in young autistic children. *Journal of Child Psychology & Psychiatry & Allied Disciplines*, 34, 563-578.
- McLoyd, V. C. (1998). Socioeconomic disadvantage and child development. *American Psychologist*, 53, 185-204.
- McNamara, T. P., & Shelton, A. L. (2003). Cognitive maps and the hippocampus. *Trends in Cognitive Sciences*, 7, 333-335.
- Meyer, J. A., & Minshew, N. J. (2002). An update on neurocognitive profiles in asperger syndrome and high-functioning autism. *Focus of Autism and Other Developmental Disabilities*, 17, 152-160.
- Minshew, N. J., Goldstein, G., Muenz, L. R., & Payton, J. B. (1992). Neuropsychological functioning of nonmentally retarded autistic individuals. *Journal of Clinical and Experimental Neuropsychology*, 14, 749-761.
- Minshew, N. J., Goldstein, G., & Siegel, D. J. (1997). Neuropsychologic functioning in autism: Profile of a complex information processing disorder. *Journal of the International Neuropsychological Society*, 3, 303-316.

- Mitchell, P., & Ropar, D. (2004). Visuo-spatial abilities in autism: a review. *Infant and Child Development, 13*, 185-198.
- Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., & Howerter, A. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: a latent variable analysis. *Cognitive Psychology, 41*, 49-100.
- Miyake, A., Friedman, N. P., Rettinger, D. A., Shah, P., & Hegarty, M. (2001). How are visuo-spatial working memory, EF, and spatial abilities related? A latent variable analysis. *Journal of Experimental Psychology, 130*, 621-640.
- Morris, R. G. M. (1984). Development of a water-maze procedure for studying spatial learning in the rat. *Journal of Neuroscience Methods, 11*, 47-60.
- Morris, R. G., Rowe, A., Fox, N., Feigenbaum, J. D., Miotto, E. C., & Howlin, P. (1999). Spatial working memory in Asperger's syndrome and in patients with focal frontal and temporal lobe lesions. *Brain and Cognition, 41*, 9-26.
- Mottron, L., Burack, J., Iarocci, G., Belleville, S., & Enns, J. (2003). Locally oriented perception and intact global processing among adolescents with high-functioning autism. *Journal of Child Psychology and Psychiatry, 42*, 253-260.
- Mottron, L., Dawson, M., Soulières, I., Hubert, B., & Burack, J. (2006). Enhanced perceptual functioning in autism: An update, and eight principles of autistic perception. *Journal of Autism and Developmental Disorders, 36*, 27-43.
- O'Keefe, J., & Nadel, L. (1978). *The Hippocampus as a Cognitive Map*. Oxford: Clarendon Press.

- Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh Handedness Inventory. *Neuropsychologia*, 9, 97-113.
- Osterrieth, P. A. (1944). Le test de copie d'une figure complexe [The complex figure copy test]. *Archives de Psychologie*, 30, 206-356.
- Ozonoff, S. (1995). Reliability and validity studies of the Wisconsin Card Sorting Task in studies of autism. *Neuropsychology*, 9, 491-500.
- Ozonoff, S., Pennington, B. F., & Rogers, S. J. (1991). Executive function deficits in high-functioning autistic individuals: Relationship to theory of mind. *Journal of Child Psychology & Psychiatry & Allied Disciplines*, 32, 1081-1105.
- Ozonoff, S., South, M., & Miller, J. N. (2000). DSM-IV-defined Asperger's syndrome: cognitive, behavioural, and early history differentiation from high-functioning autism. *Autism*, 4, 29-46.
- Ozonoff, S., & Strayer, D. L. (2001). Further evidence of intact working memory in autism. *Journal of Autism & Developmental Disorders*, 31, 257-263.
- Ozonoff, S., Strayer, D. L., McMahon, W. M., & Filloux, F. (1994). Executive function abilities in autism and Tourette's syndrome: An information processing approach. *Journal of Child Psychology and Psychiatry*, 35, 1015-1032.
- Pascualvaca, D., Fantie, B., Papageorgiou, M., & Mirsky, A. (1998). Attention capacities in children with autism: Is there a general deficit in shifting focus? *Journal of Autism and Developmental Disorders*, 28, 467-478.
- Pennington, B. F. (2002). *The development of psychopathology: Nature and nurture*. New York, NY: Guilford Press.

- Pennington, B. F., & Ozonoff, S. (1996). Executive functions and developmental psychopathology. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, 37, 51-88.
- Pennington, B. F., Rogers, S. J., Bennetto, L., Griffith, E. M., Reed, D. T., & Shyu, V. (1997). Validity tests of the executive dysfunction hypothesis of autism. In J. Russell (Ed.), *Autism as an executive disorder* (pp. 143-178). Oxford: Oxford University Press.
- Pentland, L. M., Anderson, V. A., Dye, S., & Wood, S. J. (2003). The Nine-Box Maze Test: a measure of spatial memory development in children. *Brain and Cognition*, 52, 144-154.
- Pertini, M. (2004). *Investigating spatial reasoning skills among individuals diagnosed with Asperger's syndrome*. Unpublished doctoral thesis, University of Surrey, United Kingdom.
- Piguet, O., Grayson, G., Browe, A., Tate, H., Lye, T., & Creasey, H., et al. (2002). Normal aging and executive functions in "old-old" community dwellers: Poor performance is not an inevitable outcome. *International Psychogeriatric Association*, 14, 139-159.
- Plaisted, K., Swettenham, J., & Rees, L. (1999). Children with autism show local precedence in a divided attention task and global precedence in a selective attention task. *Journal of Child Psychology and Psychiatry*, 40, 733-742.
- Prifitera, A., Weiss, L. G., & Saklofske, D. H. (1998). *WISC-III clinical use and interpretation: Scientist-practitioner perspectives*. New York, NY: Academic Press.
- Prior, M., & Ozonoff, S. (1998). Psychological factors in autism. In F. Volkmar (Ed.), *Autism and pervasive developmental disorders* (pp. 64-98). Cambridge, U.K.: Cambridge University Press.

- Psychological Corporation. (1999). *Wechsler Abbreviated Scale of Intelligence (WASI) manual*. San Antonio, TX: Author.
- Rey, A. (1941). L'examen psychologique dans les cas d'encephalopathie traumatique [Psychological examination of traumatic encephalopathy]. *Archives de Psychologie*, 28, 286-340.
- Rinehart, N. J., Bradshaw, J. L., Moss, S. A., Brereton, A. V., & Tonge, B. J. (2000). Atypical interference of local detail on global processing in high-functioning autism and Asperger's disorder. *Journal of Child Psychology and Psychiatry*, 41, 769-778.
- Ring, H. A., Baron-Cohen, S., Wheelwright, S., Williams, S. C. R., Brammer, M., Andrew, C., & Bullmore, E. T. (1999). Cerebral correlates of preserved cognitive skills in autism: a functional MRI study of embedded figures task performance. *Brain*, 122, 1305-1315.
- Roche, R. A. P., Mangaoang, M. A., Commins, S., & O'Mara, S. M. (2005). Hippocampal contributions to neurocognitive mapping in humans: a new model. *Hippocampus*, 15, 622-641.
- Rondan, C., & Deruelle, C. (2007). Global and configural visual processing in adults with autism and Asperger's syndrome. *Research in Developmental Disabilities*, 28, 197-206.
- Ropar, D., & Mitchell, P. (2001). Susceptibility to illusions and performance on visuospatial tasks in individuals with autism. *Journal of Child Psychology and Psychiatry*, 42, 539-549.
- Ruff, R. M., & Parker, S. B. (1993). Gender and age specific changes in motor speed and eye-hand coordination in adults: Normative values for the finger tapping and grooved pegboard tests. *Perceptual and Motor Skills*, 76, 1219-1230.
- Russell, J. (Eds.) (1997). *Autism as an executive disorder*. London: Oxford University Press.

- Russell, J., Jarrold, C., & Henry, L. (1996). Working memory in children with autism and moderate learning difficulties. *Journal of Child Psychology & Psychiatry & Allied Disciplines*, 37, 673-686.
- Russell, J., Jarrold, C., & Henry, L. (1999). Two intact executive functions in autism: Implication for the nature of the disorder. *Journal of Autism and Developmental Disorders*, 29, 103-112.
- Russo, N., Flanagan, T., Iarocci, G., Berringer, D., Zelazo, P. D., & Burack, J. A. (2007). Deconstructing executive deficits among persons with autism: Implications for cognitive neuroscience. *Brain and Cognition*, 65, 77-86.
- Salthouse, T. A., Atkinson, T. M., & Berish, D. E. (2003). EF as a potential mediator of age-related cognitive decline in normal adults. *Journal of Experimental Psychology: General*, 132, 566-594.
- Salthouse, T. A., Fristoe, N., McGuthry, K. E., Hambrick, D. Z. (1998). Relation of task switching to speed, age, and fluid intelligence. *Psychology and Aging*, 13, 445-461.
- Sattler, J. M. (1992). *Assessment of children* (3rd ed.). San Diego, CA: Author.
- Schlooz, A. J. M., Hilstijn, W., van den Broek, P. J. A., van der Pijll, A. C. A. M., Gabreels, F., van der Gaag, R. J., & Rotteveel, J. J. (2006). Fragmented visuospatial processing in children with Pervasive Developmental Disorder. *Journal of Autism and Developmental Disorders*, 36, 1025-1037.
- Schneider, S. G., & Asarnow, R. F. (1987). A comparison of cognitive/ neuropsychological impairments of nonretarded autistic and schizophrenic children. *Journal of Abnormal Child Psychology*, 15, 29-46.

- Schopler, E., Reichler R. J., & Renner, B. R. (1992). *The Childhood Autism Rating Scale*. Los Angeles: Western Psychological Services.
- Shah, A., & Frith, U. (1983). An islet of ability in autistic children: A research note. *Journal of Child Psychology and Psychiatry*, 24, 613-620.
- Shah, A., & Frith, U. (1993). Why do autistic individuals show superior performance on the block design test? *Journal of Child Psychology and Psychiatry*, 34, 1351-1364.
- Sigman, M., Spence, S. J., & Ting Wang, A. (2006). Autism from developmental and neuropsychological perspectives. *Annual Review of Clinical Psychology*, 2, 327-355.
- Skelton, R. W., Bukach, C. M., Laurance, H. E., Thomas, K. G. F., Jacobs, J. (2000). Humans with traumatic brain injuries show place learning deficits in computer generated virtual space. *Journal of Clinical Experiments in Neuropsychology*, 22, 157-175.
- Stano, J. F. (2004). Test review: Wechsler Abbreviated Scale of Intelligence. *Rehabilitation Counseling Bulletin*, 48, 56-57.
- Stuss, D., & Alexander, M. P. (2000). Executive functions and the frontal lobes: a conceptual view. *Psychological Research*, 63, 289-298.
- Subrahmanyam, K., & Greenfield, P. M. (1994). Effect of video game practice on spatial skills in girls and boys. *Journal of Applied Developmental Psychology*, 15, 13-32.
- Thomas, K. G. F. (2003). Cognitive mapping and spatial navigation in patients with anterior temporal lobectomy (Doctoral dissertation, University of Arizona, 2002). *Dissertation Abstracts International*, 64, 2409.

- Thomas, K. G. F., Hsu, M., Laurence, H. E., Nadel, L., & Jacobs, W. J. (2001). Place learning in virtual space III: Investigation of spatial navigation training procedures and their application to fMRI and clinical neuropsychology. *Behaviour Research Methods, Instruments, and Computers*, 33, 21-37.
- Tonn, R. T., & Obrzut, J. E. (2005). The neuropsychological perspective on autism. *Journal of Developmental and Physical Disabilities*, 17, 409-419.
- Van Lang, N. D., Bouma, A., Sytema, S., Kraijer, D. W., & Minderaa, R. B. (2006). A comparison of central coherence skills between adolescents with an intellectual disability with and without comorbid autism spectrum disorder. *Research in Developmental Disorders*, 27, 217-226.
- Wechsler, D. (1991). *Wechsler Intelligence Scale for Children – Third Edition*. San Antonio, TX: Psychological Corporation.
- Williams, D. L., Minshew, N. J., & Goldstein, G. (2006). The profile of memory function in children with autism. *Neuropsychology*, 20, 21-29.
- Witkin, H. A., Oltman, P. K., Raskin, E., & Karp, S. A. (1971). *A manual for the embedded figures tests*. Palo Alto, CA: Consulting Psychologists Press.
- Yerys, B. E., Hepburn, S. L., Pennington, B. F., & Rogers, S. J. (2007). Executive function in preschoolers with autism: Evidence consistent with secondary deficit. *Journal of Autism and Developmental Disorders*, 37, 1068-1079.

APPENDIX A**DSM-IV-TR (APA, 2000) Diagnostic Criteria for Autistic Disorder**

A. A total of six (or more) items from (1), (2), and (3), with at least two from (1), and one each from (2) and (3):

1. Qualitative impairment in social interaction, as manifested by at least two of the following:

- a. marked impairment in the use of multiple nonverbal behaviours such as eye-to-eye gaze, facial expression, body postures, and gestures to regulate social interaction**
- b. failure to develop peer relationships appropriate to developmental level**
- c. a lack of spontaneous seeking to share enjoyment, interests, or achievements with other people (e.g., by a lack of showing, bringing, or pointing out objects of interest)**
- d. lack of social or emotional reciprocity**

2. Qualitative impairments in communication as manifested by at least one of the following:

- a. delay in, or total lack of, the development of spoken language (not accompanied by an attempt to compensate through alternative modes of communication such as gestures or mime)**
- b. in individuals with adequate speech, marked impairment in the ability to initiate or sustain a conversation with others**
- c. stereotyped and repetitive use of language or idiosyncratic language**
- d. lack of varied, spontaneous make-believe play or social imitative play appropriate to developmental level**

3. Restricted repetitive and stereotyped patterns of behaviour, interests, and activities, as manifested by at least one of the following:

- a. encompassing preoccupation with one or more stereotyped and restricted patterns of interest that is abnormal either in intensity or focus**
- b. apparently inflexible adherence to specific, nonfunctional routines or rituals**
- c. stereotyped and repetitive motor mannerisms (e.g. hand or finger flapping or twisting, or complex whole-body movements)**
- d. persistent preoccupation with parts of objects**

B. Delays or abnormal functioning in at least one of the following areas, with onset prior to age 3 years: (1) social interaction, (2) language as used in social communication, or (3) symbolic or imaginative play.

C. The disturbance is not better accounted for by Rett's Disorder or Childhood Disintegrative Disorder.

APPENDIX B**DSM-IV-TR (APA, 2000) Diagnostic Criteria for Asperger's Syndrome****A. Qualitative impairment in social interaction, as manifested by at least two of the following:**

- 1. Marked impairment in the use of multiple nonverbal behaviours such as eye-to-eye gaze, facial expression, body postures, and gestures to regulate social interaction**
- 2. Failure to develop peer relationships appropriate to developmental level**
- 3. A lack of spontaneous seeking to share enjoyment, interests, or achievements with other people (e.g., by a lack of showing, bringing, or pointing out objects of interest to other people)**
- 4. Lack of social or emotional reciprocity**

B. Restricted repetitive and stereotyped patterns of behaviour, interests, and activities, as manifested by at least one of the following:

- 1. Encompassing preoccupation with one or more stereotyped and restricted patterns of interest that is abnormal either in intensity or focus**
- 2. Apparently inflexible adherence to specific, nonfunctional routines or rituals**
- 3. Stereotyped and repetitive motor mannerisms (e.g., hand or finger flapping or twisting, or complex whole-motor movements)**
- 4. Persistent preoccupation with parts of objects**

C. The disturbance causes clinically significant impairment in social, occupational, or other important areas of functioning.**D. There is no clinically significant delay in cognitive development or in the development of age-appropriate self-help skills, adaptive behaviour (other than in social interaction), and curiosity about the environment in childhood.****E. Criteria are not met for another specific Pervasive Developmental Disorder or Schizophrenia.**

APPENDIX C

Letter of Permission to Conduct Research in Western Cape Schools

Name: Dr R.S. Cornelissen
 Engelse: Dr R.S. Cornelissen
 Afrikaans:
 Telefoon: (021) 467-3286
 Telefoon: (021) 467-3286
 Faks:
 Fax: (021) 425-7445
 E-pos:



Wes-Kaap Onderwysdepartement

Western Cape Education Department

Isibhe leMfundo leNtshona Koloni

Verwysing: 2006/721-0043
 Referensie:
 Stelselno:

Miss Michelle Daniels
 9 Shannon Mews
 Lower York Road
 ROSE BANK
 7700

Dear Miss M. Daniels

RESEARCH PROPOSAL: SPATIAL COGNITION AND NAVIGATION IN AUTISM SPECTRUM DISORDER

Your application to conduct the above-mentioned research in schools in the Western Cape has been approved subject to the following conditions:

1. Principals, educators and learners are under no obligation to assist you in your investigation.
2. Principals, educators, learners and schools should not be identifiable in any way from the results of the investigation.
3. You make all the arrangements concerning your investigation.
4. Educational programmes are not to be interrupted.
5. The Study is to be conducted from 24th July 2006 to 22nd September 2006.
6. No research can be conducted during the fourth term as schools are preparing and finalizing syllabi for examinations (October to December 2006).
7. Should you wish to extend the period of your survey, please contact Dr R. Cornelissen at the contact numbers above quoting the reference number.
8. A photocopy of this letter is submitted to the Principal where the intended research is to be conducted.
9. Your research will be limited to the following schools: Alpha School and Vera School.
10. A brief summary of the content, findings and recommendations is provided to the Director: Education Research.
11. The Department receives a copy of the completed report/dissertation/thesis addressed to:

The Director: Education Research
 Western Cape Education Department
 Private Bag X3114
 CAPE TOWN
 8000

We wish you success in your research.

Kind regards,

Signed: Ronald S. Cornelissen
 for: HEAD: EDUCATION
 DATE: 04th August 2006

MIETJES AANVAARD VERWYDINGNUMMERS IN ALLE KORRESPONDENSIE / PLEASE QUOTE REFERENCE NUMBERS IN ALL CORRESPONDENCE /
 MOEDER: OORNAME VERWYDINGNUMMERS IN ALLE KORRESPONDENSIE

GRAND CENTRAL TOWERS, LAER-Parlementstraat, Private Bag X3114, Kaapstad 8000
 GRAND CENTRAL TOWERS, LOWER PARLIAMENT STREET, PRIVATE BAG X3114, CAPE TOWN 8000

WEB: <http://www.wced.gov.za>

INTELSENTRUM / CALL CENTRE

INDIENENEMING- EN SALARISNAVRAE/EMPLOYMENT AND SALARY QUERIES ☎0061 92 33 22

10000 10000 10000 10000 10000 10000 10000 10000 10000 10000

APPENDIX D

Letter of Permission to Conduct Research in Gauteng Schools

06-03-'07 13:35 FBH

T-312 PR2/03 U-691



UMayango Wamkhando
Department of Education

Lefapha la Thuto
Departement van Onderwys

Date:	14 February 2007
Name of Researcher:	Dorinda Schutte
Address of Researcher:	101 Albert Road, Waverley Street Rosebank Park Johannesburg
Telephone Number:	0117687888
Fax Number:	0117752288
Research Topic:	Spoken Narration in Autism Spectrum Disorders
Number and type of schools:	2 Primary Schools
District/HQ:	Johannesburg South, West & North

Re: Approval in Respect of Request to Conduct Research

This letter serves to indicate that approval is hereby granted to the above-mentioned researcher to proceed with research in respect of the study indicated above. The once made with the researcher to negotiate appropriate and relevant time arrangements with the relevant sector offices involved to conduct the research. A separate copy of the letter will be presented to both the School (both Principal and GBO) and the District/Local Office Sector Manager confirming that permission has been granted for the research to be conducted.

Permission has been granted to proceed with the above study subject to the conditions stated below being met, and may be withdrawn should any of these conditions be breached:

1. The District/Local Office Sector Manager concerned must be presented with a copy of this letter that would indicate that the said researcher has been granted permission from the Gauteng Department of Education to conduct the research study.
2. The District/Local Office Sector Manager must be approached separately, and in writing, for permission to involve District/Local Office Officials in the project.
2. A copy of this letter must be forwarded to the school principal and the chairperson of the School Governing Body (SGB) that would indicate that the researcher has been granted permission from the Gauteng Department of Education to conduct the research study.

Director: Knowledge Management and Research
Room 628, 111 Commissioner Street, Johannesburg, 2001 P.O. Box 7715, Johannesburg, 2000
Tel (011) 309-0400 Fax (011) 309-0400

4. A letter / document that contains the purpose of the research and the anticipated outcomes of such research must be made available to the principal, SGRS and District/Local Office Senior Managers of the schools and districts/units concerned respectively.
5. The Researcher will make every effort during the planning and co-operation of all the GDE officials, principals, and chairpersons of the SGRS, teachers and learners involved. However, the other staff co-operation will not involve additional remuneration from the Department unless there is a need to participate and not be provided in any way.
6. Research may only be conducted after approval having been given by the principal of the school/department. The Principal or at a school level Senior Manager or at a district/department level must be consulted about any expenditure then when the researcher may want to use resources of the school or department.
7. Research may not be conducted from the school/department of the school/department unless the Principal or at a school level Senior Manager or at a district/department level has approved the research project.
8. Research may not be conducted in any/department after having undertaken on behalf of the GDE, but research will have been conducted and be paid for by the District/Department of Education.
9. If a researcher is responsible to obtain written parental consent of all learners that are expected to participate in the study.
10. The researcher is responsible for planning and managing research using resources, such as a laboratory, instruments, computer, maps and materials and should not depend on the provision of the Department and/or the school/department for completed work resources. The nature of the work includes, research, research, research, research and research. The principal of the school/department and support in the research report without the written consent of each of these stakeholders, senior management.
11. On completion of the study the researcher must supply the Senior Manager, District/Department, Department, a Research Committee with the final report and one copy must be kept in the school/department report. The researcher must also provide the final manager with an identical copy of the research/departmental report.
12. The researcher may be expected to provide short presentations of the progress, findings and recommendations of his/her research to both GDE officials and the schools concerned.
13. The researcher must have been involved with research at a school/department/district/department level, the Senior Manager/Principal must also be supplied with a brief summary of the progress, findings and recommendations of the research study.

The Gauteng Department of Education wishes you well in this important undertaking and looks forward to examining the findings of your research study.

Kind regards

signature removed

ACTING CHIEF DIRECTOR: O-STEED

This document of this letter has been read and understood by the researcher:	
Signature of Researcher:	signature removed
Date:	19/03/07

APPENDIX E
Demographic Questionnaire

Participant no.: _____ Date: _____

Demographic Questionnaire

Please fill in or tick the following as appropriate:

A. Child's Information:

1) Name: _____

2) Age: _____

3) Date of Birth (day/month/year): ____/____/____

4) Sex:

- ☐ Male
☐ Female

5) Home Language: _____

6) Ethnicity:

- ☐ White
☐ Black
☐ Indian
☐ Coloured
☐ Asian
☐ Other

If other please specify: _____

7) Which school your child is currently attending? _____

8) Grade: _____

9) How long has he/she attended this school? _____

10) Which school(s) has he/she (if any) attended previously? _____

11) How often does your child use a computer?

- ☐ Never ☐ A few times a year ☐ Once a month ☐ Once a week ☐ Every day

APPENDIX F
NBMT-CV Score Sheet

Participant no.: _____ Date: _____

Object Familiarization:

Instructions:

1. "I am going to show you some things that I want you to remember."
(10 sec presentation)
2. "What is it?"/ "Would you play with it?"
(1 minute delay before recall filled with talk, collecting stickers etc.)
3. "What things did I show you before?"

ITEM	RECALL ORDER
1. car	
2. spoon	
3. apple	
4. lollipop	
5. ball	
6. book	
7. marker	
8. toothbrush	
9. teddy	
10. cup	
TOTAL RECALLED	

Five Box Maze Trials

Trial	Presentation			Recall				
	Seat	Object	Location	Obj F	Obj Rec	Loc	O&L	Total
1	1 → 3	Spoon	3					
		Ball	1					
2	3 → 2	Marker	2					
		Book	4					
3	2 → 4	Spoon	1					
		Apple	5					
Total								

Instructions:

1. "I am going to put two things into two separate containers, then get you to change seats and tell me which things were hidden and in which bins."
2. Place items in containers, secure lids, and reseal participant.
3. "Which things were hidden?" (Well done) Or 4. "Which of the things in this picture is the other hidden object(s)?"
5. "Point to the containers with things in them." (Well done)
6. "Which things were hidden in which containers?" (Well done-reveal hidden objects)

Array:

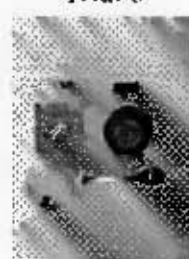
Trial 1



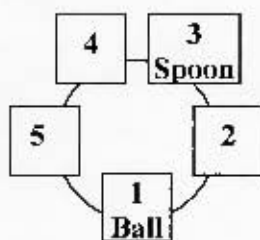
Trial 2



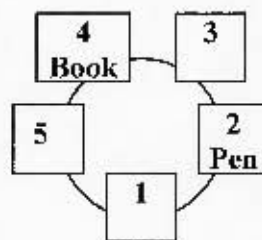
Trial 3

Layout:

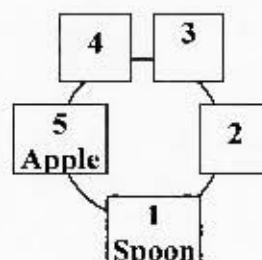
Trial 1



Trial 2



Trial 3



Nine Box Maze Trials

Presentation				Recall				
Trial	Seat	Object	Location	Obj F	Obj R	Loc	O&L	Total
1	1 → 2	Cup*	9					
		Teddy	3*					
		Car*	8*					
		Toothbrush	7					
2	2 → 4	Cup*	1					
		Spoon	8*					
		Car*	4					
		Ball	3*					
3	4 → 3	Apple	2					
		Cup*	8*					
		Toothbrush	6					
		Car*	3*					
4	3 → 4	Book	2					
		Car*	9					
		Cup*	8*					
		Spoon	3*					
Total								

Instructions:

1. "I am going to put two things into two separate containers, then get you to change seats and tell me which things and which bins were used."
2. Place items in unlidded containers, secure lids, and reseal participant.
3. "Which things were hidden?" (Well done) Or 4. "Which of the objects in this picture is the other hidden object(s)?"
5. "Point to the containers with things in them?" (Well done)
6. "Which things were hidden in which bins?" (Well done- reveal hidden items)

Arrays:

Trial 1



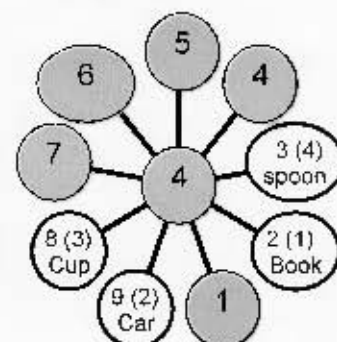
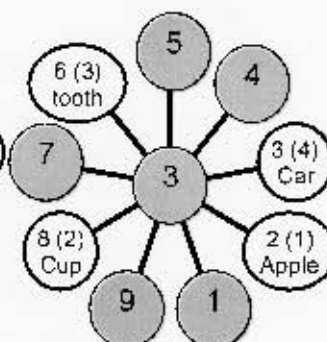
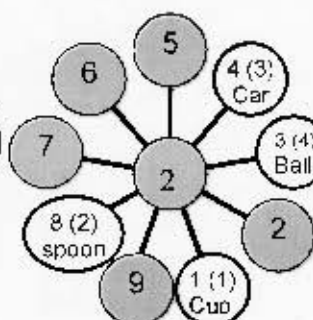
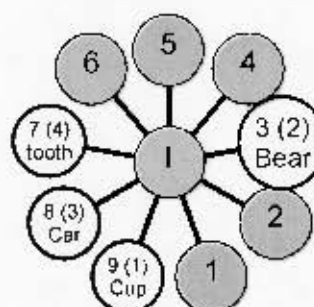
Trial 2



Trial 3



Trial 4



APPENDIX G**Information/Consent Form: ASD Groups****RE: Research study**

Dear Parent(s),

Researchers from the University of Cape Town are carrying out a study on how children with Autism Spectrum Disorder learn about, remember, and move through their everyday environments. We have obtained permission from the governing body of School, relevant ethics committees at UCT, and the Western Cape Education Department to conduct this research. We would like to know if you are willing to allow your child to take part in this study.

Here are some more details about the study: We are hoping to recruit approximately 25 children with Autism Spectrum Disorder, 6-16 years of age, for our study. Children who participate in the study will be asked to complete paper-and-pencil and computer-based tasks that measure spatial ability and memory. Each child will be tested individually, in a classroom, at his/her own pace, under the supervision of his/her tutor. If at any point during the study your child finds any of the measures uncomfortable or feels tired, he/she is free to stop taking part or to take a break. We will also ask you or your child's teacher to fill out some background information questionnaires.

It is up to you whether to allow your child to take part in this study. If you do so, you and/or your child are free to stop participation at any time. If your child does not take part in the study, or takes part and then chooses to withdraw, it will not affect his/her academic care or schooling. If your child does take part, all information gathered about him/her will be kept confidential.

At the end of the study, you and Vera School will have the opportunity to get individual, verbal feedback about the findings. Ultimately, we hope our research will improve our understanding of autism and inform future treatment.

If you have any questions about the information in this letter or about the study in general, please do not hesitate to contact either of the researchers:

Kevin G. F. Thomas, Ph.D. (principal investigator)
Senior Lecturer
Department of Psychology
Tel: 021-650-4608 and 021-650-3430
Email: Kevin.thomas@uct.ac.za

Michelle Daniels
Honours Student
Department of Psychology
Tel: 082 334 0891
Email: daniels.michelle@gmail.com

If you would like to allow your child to participate in this study, please complete the attached consent form. Once filled in, please return the consent form to School as soon as possible before You may keep this information and contact sheet so that you are able to contact the researchers at any time during the study.

Thank you for your time and for considering allowing your child to participate in our study. We appreciate your help!

Sincerely,

Michelle Daniels

Kevin Thomas

University of Cape Town

CONSENT FORM

Title of study: *Spatial Cognition and Navigation in Autism Spectrum Disorder*

Please fill in the following:

Child's full name: _____

Teacher at Vera School: _____

- You have been informed about this study's purpose, procedures, possible benefits, and risks, and how your child's performance and other data will be collected, used and shared with others.
- You have received a copy of this form. You have been given the opportunity to ask questions before you sign. You have been told you can ask other questions at any time.
- You voluntarily consent to allow your child to participate in this study. You hereby authorize the collection, use and sharing of your child's performance and other data. By signing this form, you are not waiving any of your legal rights.

Name of Parent/Guardian Signature Date

Name of Researcher/
Person taking consent Signature Date

**PLEASE RETURN THIS COMPLETED FORM TO SCHOOL
AS SOON AS POSSIBLE BEFORE FRIDAY**

Would you like to be notified of future studies carried out by our research group?
_____ (initial) Yes, I would like to be added to your research participation pool
and be notified of research projects in which my child or I might participate in the future.

Method of contact:

Phone number: _____ E-mail address: _____

Mailing address: _____

APPENDIX H

Information/Consent Form: non-ASD Groups

RE: Research study

Dear Parent(s),

Researchers from the University of Cape Town are carrying out a study on how children with Autism Spectrum Disorder learn about, remember, and move through their everyday environments compared to healthy children of the same age. The relevant ethics committees at UCT, as well as the staff of School have approved this study. We would like to know if you are willing to allow your child to take part in this study as part of the comparison group of children who do not have autism.

Here are some more details about the study: We are hoping to recruit approximately 25 children, 7-13 years of age, for our study. Children who participate in the study will be asked to complete paper-and-pencil and computer-based tasks that measure spatial ability and memory. Each child will be tested individually, in a classroom, at his own pace. If at any point during the study your child finds any of the measures uncomfortable or feels tired, he is free to stop taking part or to take a break. We will also ask you, your child, or your child's teacher to fill out some background information questionnaires.

It is up to you whether to allow your child to take part in this study. If you do so, you and/or your child are free to stop participating at any time. If your child does not take part in the study, or takes part and then chooses to withdraw, it will not affect his academic care or schooling. If your child does take part, all information gathered about him will be kept confidential.

At the end of the study, you and St Josephs will have the opportunity to get individual, verbal feedback about the findings. Ultimately, we hope our research will improve our understanding of autism and inform future treatment.

If you have any questions about the information in this letter or about the study in general, please do not hesitate to contact either of the researchers:

If you would like to allow your child to participate in this study, please complete the attached consent form. Once filled in, please return the consent form to as soon as possible before You may keep this information and contact sheet so that you are able to contact the researchers at any time during the study.

Thank you for your time and for considering allowing your child to participate in our study. We appreciate your help!

CONSENT FORM

Title of study: *Spatial Cognition and Navigation in Autism Spectrum Disorder*

Please fill in the following:

Child's full name: _____ **Age:** _____

Handedness: _____

Grade: _____

- You have been informed about this study's purpose, procedures, possible benefits, and risks, and how your child's performance and other data will be collected, used and shared with others.
- You have received a copy of this form. You have been given the opportunity to ask questions before you sign. You have been told you can ask other questions at any time.
- You voluntarily consent to allow your child to participate in this study. You hereby authorize the collection, use and sharing of your child's performance and other data. By signing this form, you are not waiving any of your legal rights.

Name of Parent/Guardian

Signature

Date

Name of Researcher/
Person taking consent

Signature

Date

**PLEASE RETURN THIS COMPLETED FORM TO ST JOSEPHS
AS SOON AS POSSIBLE BEFORE**

Would you like to be notified of future studies carried out by our research group?
_____ (initial) Yes, I would like to be added to your research participation pool
and be notified of research projects in which my child or I might participate in the future.

Method of contact:

Phone number: _____ E-mail address: _____

Mailing address: _____

APPENDIX I

Rey Complex Figure- Organisational Strategy Score (RCF-OSS; P. Anderson, et al., 2001)

General Information

The vertical and horizontal centerlines are pivotal to organization of the drawing and significant components of RCF-OSS.

The accuracy of drawing is not being measured, consequently parts of figure may be missing or drawn incorrectly.

The orientation of drawing may be incorrect.

The examiner should carefully record sequence in which figure is completed.

Retrospective scoring can often increase rating difficulty.

Definitions

Rectangle: Refers to large rectangle and is a configural component of figure.

Centerlines: Refers to vertical and horizontal bisectors of rectangle. Centerlines are also configural components of figure, and separately drawn portions must connect.

Contour: Refers to outline of figure. This may (or may not) include total outline, such as cross, diamond, or triangle.

Diagonals: Refers to diagonals of rectangle. Diagonals do not have to be completed as single whole lines and sections of each diagonal do not have to connect.

Outside attachments: Refers to all sections of figure external to rectangle, includes left vertical cross; horizontal cross below rectangle; triangle on top of rectangle; triangle on right side of rectangle; small box below rectangle.

Internal sections: Refers to all internal sections of large rectangle which could be divided into half, quarters or eighths. This includes: four parallel lines and small horizontal line in left upper quadrant; circle with three dots and small vertical line in right upper quadrant; rectangle with diagonals in left upper and lower quadrants; five parallel lines along diagonal in right lower quadrant.

Alignment: Refers to an "attempt" (i.e., perfect execution not necessary) to align or connect outside attachments and internal sections with centerlines. Alignment of diagonals refers to an "attempt" to connect sections of each diagonal at midpoint junction of vertical and horizontal centerlines.

RCF-OSS Instructions

Level 7 - excellent organization. Configural elements, the rectangle and centerlines, are completed first

- Criteria:** (a) rectangle is drawn first (may include the left hand cross);
 (b) both vertical and horizontal centerlines are drawn directly after the rectangle;
 (c) all of the internal sections, outside attachments and the diagonals aligned with centerlines.

Level 6 - conceptual organization. Vertical and horizontal centerlines are drawn early.

- Criteria:** (a) either rectangle, contour, an internal section or outside attachments is drawn first;
 (b) both centerlines are drawn as whole single lines and completed prior to drawing diagonals and internal sections;
 (c) diagonals are aligned with centerlines (i.e., meet at the midpoint junction);
 (d) majority of internal sections and outside attachments are aligned with centerlines.

Level 5 - part-configural organization. Vertical and horizontal centerlines are present.

- Criteria:** (a) either rectangle, contour, an internal section or outside attachment is drawn first;
 (b) both centerlines are present;
 (c) at least one internal section or outside attachment is aligned with vertical centerline, and at least one internal section or outside attachment is aligned with horizontal centerline;
 (d) at least one centerline is drawn as a whole single line, whilst remaining centerline can be completed fragmentally (i.e., in segments), although portions must connect.
 (e) a piecemeal approach is not adopted.

Level 4 - piecemeal / fragmented organization. Piecemeal, fragmented or part-whole approach (subunits/sections are drawn sequentially piece by piece).

- Criteria:** (a) either rectangle, contour, an internal section or outside attachment is drawn first;
 (b) only one centerline is completed as a whole single line unless the contour or rectangle is completed first, in which case, neither centerline can be completed as a whole;
 (c) remaining internal sections and outside attachments are completed one at a time in a piecemeal manner (subsequent sections of drawing can be aligned with segments of centerlines).

Level 3 - random organization. Only one complete centerline is used for alignment.

- Criteria:** (a) either rectangle, contour, an inside section or outside attachment is drawn first;
- (b) one complete centerline aligned with at least one internal section/outside attachment is present (centerline can be completed fragmentally, i.e., in segments, although segments must connect);
- (c) remaining centerline, if present, is not utilized for alignment of other components;
- (d) if present, segments of an incomplete centerline can be utilized to align sections of drawing;
- (e) piecemeal approach is not adopted.

Level 2 - poor organization. Criteria for levels 3 to 7 have not been satisfied.

- Criteria:** (a) any attempt to draw figure;
- (b) any part of figure is drawn first;
- (c) if present centerlines are not aligned to any of internal sections or outside attachments;
- (d) piecemeal approach is not adopted.

Level 1 - unrecognizable or substitution. No attempt is made to draw figure. Child may draw a substitution or an unrecognizable scrawl.

APPENDIX J

Glossary of Acronyms

ASD	Autism Spectrum Disorder
HFA	High-functioning autism
LFA	Low-functioning autism
AS	Asperger's syndrome
TD	Typically developing
MR	Mental retardation
EF	Executive function
WCC	Weak central coherence
FSIQ	Full scale Intelligence Quotient
PIQ	Performance Intelligence Quotient
VIQ	Verbal Intelligence Quotient
WASI	Wechsler Abbreviated Scale of Intelligence
GPT	Grooved Pegboard Test
WCST ⁶⁴	Wisconsin Card Sorting Task ⁶⁴
ToL	Tower of London
ROCF-OSS	Rey-Osterrieth Complex Figure- Organisational Strategy Score
BD	Block Design
CEFT	Children's Embedded Figures Test
ROCF	Rey-Osterrieth Complex Figure
FBMT	Five Box Maze Test
NBMT-CV	Nine Box Maze Test- Child Version
SRL	Spatial Response Learning
SPC	Spatial Place Coding
CG Arena	Computer-Generated Arena
ORT	Object Recognition Task
ART	Area Reconstitution Task