Wayfinding in Autism Spectrum Disorders

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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: ____________________ Date: _______________

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ABSTRACT

The neuropsychology of autism spectrum disorders (ASD) is a field that features lively debate; for instance, the question of whether autistic children have impaired, intact, or superior spatial cognitive abilities remains unanswered due to inconsistent findings from several recent empirical studies. These studies, however, have tended to feature only high-functioning autistic children and/or those with a diagnosis of Asperger's syndrome, thus limiting their ability to generalize to the entire population of ASD children. Furthermore, previously published studies have tended to focus on a limited number of spatial abilities, rather than using a comprehensive battery testing a wide range of such abilities. This study featured the use of such a comprehensive battery, designed to assess general spatial ability as well as varieties of spatial cognition (including spatial navigation). The battery was administered to participants in six age- and sex-matched groups: low-functioning autistic (LFA) children, high-functioning autistic (HFA) children, children with Asperger's syndrome (AS), children with Pervasive Developmental Disorder Not Otherwise Specified (PDD-NOS), DSM-defined Mildly Mentally Retarded (MR) children, and typically developing (TD) children (n = 15 per group). Results showed that the LFA participants performed similarly to the MR participants on most tests of spatial cognition, including spatial navigation, and did not make use of alternative search strategies during navigation in comparison to MR children. The HFA and PDD-NOS participants, however, performed more poorly than the TD and AS participants on most of the tasks, except on the spatial navigation task where they displayed intact abilities. The results are discussed in terms of how the obtained data both confirm and disconfirm the predictions made by both central coherence theories and the enhanced perceptual functioning theory of ASD neurocognitive functioning. These data suggest that, contrary to theories of weak central coherence and enhanced perceptual functioning, certain ASD individuals have intact but not superior spatial cognitive abilities.

Keywords: autism spectrum disorder; spatial cognition; low-functioning ASD; high-functioning ASD; allocentric; egocentric.

BACKGROUND

Autism is a complex and diverse biological disorder that is defined by various behavioural symptoms and deficits that affect the development of an individual. According to the Diagnostic and Statistical Manual of Mental Disorders (Fourth Edition, Text Revision; DSM-IV-TR; American Psychiatric Association [APA], 2000), autism is characterised by three core deficits: in social interaction, communication, and restricted repetitive behaviour. There are various other characteristics of DSM-defined autism spectrum disorders (ASDs) aside from the core deficits, such as abnormal symbolic or imaginative play that may be present upon diagnosis (see Appendix A for the full DSM-IV-TR diagnostic criteria). In order for a positive diagnosis to be made, the three core impairments of ASD must be present before an individual is 3 years old; in practice, however, diagnoses are often only made at a later stage.

Autism is "one of several pervasive developmental disorders (PDD's) caused by a dysfunction of the central nervous system leading to disordered development" (Kabot, Masi, & Segal, 2003, p. 26). The DSM-IV-TR lists four other pervasive developmental disorders: Rett's disorder, Asperger's syndrome, childhood disintegrative disorder and pervasive developmental disorder - not otherwise specified (PDD-NOS). Classical autism, Asperger's syndrome, and PDD-NOS all fall under the broad category of ASD.

A certain set of behaviours or symptoms can be used to describe autistic individuals; these behaviours can range from mild to severe. Aside from the core deficits, individuals on the autism spectrum may present with all the common symptoms typical of the ASD diagnosis, or they may present with only a few of these symptoms (National Institute of Mental Health [NIMH], 2007). Therefore, the various symptoms may be present in different combinations in each ASD individual (Kabot et al., 2003). Different combinations of symptoms help identify into which ASD subtype the child fits; hence, in making a diagnostic decision, clinicians should focus not only on the *severity* of symptoms, but also on the *types* of symptoms that are present and not present (Witwer & Lecavalier, 2008).

The symptoms of autism may be classified, broadly, as either positive or negative. Negative symptoms include impairments in specific domains of social and communicative functioning (e.g., failing to form a relationship with a peer, or lacking spontaneous, make-believe imaginative play). Positive symptoms include cognitive strengths present in children with ASD. These are characteristics that an autistic individual may possess that a typically developing individual may not possess (e.g., the restricted repetitive behaviours and interest or a fixed interest in specific parts of objects; Bertone, Faubert, Jelenic & Mottron, 2005; Bonnel et al., 2003).

Autism is therefore viewed as a spectrum disorder because of the variety of behaviours and symptoms associated with it, and the varying degrees to which each affected individual displays those behaviours and symptoms. From a cognitive perspective, individuals on the autism spectrum have varying levels of intelligence and language ability (Hill & Frith, 2003). Low-functioning autistic (LFA) individuals typically have IQ scores of 70 or below and are often likely to display at least mild mental retardation. Overall, 70% of autistic individuals have been reported to have an IQ of below 70 (Brosnan, Scott, Fox, & Pye, 2004). High-functioning autistic (HFA) individuals usually have an IQ score of higher than 75 and have better adaptive functioning than low-functioning autistic individuals.

Asperger’s syndrome (AS) is a milder form of autism that typically features similar, but not as many, characteristics of more severe forms of the disorder (Frith & Vignemont, 2005). Individuals diagnosed with AS possess the same social and imagination impairments present in classical autism, and frequently have obsessive and narrow interests, but display normal development of language skills, as well as normal intellectual functioning in childhood (i.e., an average or above-average IQ; Hill & Frith 2003; Macintosh & Dissanayake, 2004; Pertini, 2004). AS is often only diagnosed later on in childhood and there is often confusion between a diagnosis of HFA and AS (see Appendix B for the full DSM-IV-TR diagnostic criteria for AS; Marker, Weeks, & Kraegal 2007).

Individuals diagnosed with PDD-NOS may or may not display severe symptoms in the domains typically affected in autistic individuals; for instance, they may have difficulty developing appropriate social interaction, and/or display impaired verbal or non-verbal communication, and/or display stereotyped and repetitive behaviour (Luteijn et al., 2000). Individuals that fall within this category usually do not meet the full criteria for another pervasive developmental disorder such as autism, AS, Rett’s disorder, or childhood disintegrative disorder. Numerous problems plague this diagnostic category, including the facts that the criteria used to make a diagnosis is vague, and that the individuals falling within this category form a heterogeneous rather than homogenous group (see Appendix C for full DSM-IV-TR diagnostic criteria for PDD-NOS; Witwer & Lecavalier, 2008).

As should be clear from the brief review above, making a differential diagnosis within the broad category of ASD can be difficult for clinicians. For example, one of the main DSM-IV diagnostic criteria used for differentiating between AS and HFA includes the lack of a language delay in the former. However, when a diagnosis is made later in the child’s life, it is not easy to establish whether a language delay was present earlier, thus making the differential diagnosis difficult. This is just one example of the types of difficulties emerging from the current diagnostic criteria. Another example is the diagnosis of PDD-NOS. This diagnostic category is meant to include individuals who do not meet the full diagnostic criteria for autism; there are no specific diagnostic criteria associated with it. Therefore, individuals diagnosed with PDD-NOS can have disabilities that range from mild to severe and atypical. Again, this situation illustrates the point that it is extremely challenging, given the current diagnostic systems, for clinicians to provide accurate diagnoses for ASD individuals who do not meet the full criteria for autism.

Witwer and Lecavalier (2008), in a paper reviewing the validity of ASD subtypes, showed that there are inconsistencies in how professionals classify a child with autism, and that there is therefore a need for diagnostic criteria to be used consistently by professionals when assessing children with autism. For example, they pointed out that different studies tend to make use of different diagnostic criteria, leading to inconsistencies in the diagnosis of individuals and uncertainty among professionals as to, for instance, how to classify a child who meets all the criteria for autism yet does not present with cognitive deficits or with a language delay. The review further showed that some professionals were using DSM-based criteria, whereas others were using modified criteria. Witwer and Lecavalier (2008) concluded their review by asserting the need for stricter diagnostic criteria to be developed and used. The same differential diagnostic problems that plague clinical practice are, of course, also present in autism research.

Another issue that is present within autism research is a lack of study of individuals from across the entire spectrum. As a result of the difficulty in distinguishing between the separate groups of disorders (LFA, HFA, AS, PDD-NOS) within the spectrum of autistic disorders, many studies only make use of either LFA individuals or HFA individuals or children with AS. Specifically, behavioural studies usually only use HFA individuals due to their better adaptive functioning and because individuals with severe mental dysfunction (e.g., LFA individuals) often have a “limited repertoire and range of observable behaviour” (Hill & Frith, 2003, p. 282). Neuroimaging studies, on the other hand, make use of both HFA and LFA individuals (see Brambilla et al., 2003 for a review). Thus, problems can occur when trying to link behavioural impairment in LFA individuals with dysfunction in specific brain regions (which has only been examined in HFA and AS individuals), making it difficult to generalise findings from behavioural studies to the population of LFA individuals.

Cognitive Theories of ASD

Various theories attempt to explain the triad of core ASD deficits as they try to give explanations as to the complex behavioural patterns present in autism disorders (Happe & Frith, 1996).

The Weak Central Coherence (WCC; Frith, 1989) theory is one of the dominant frameworks that attempts to explain the neuropsychological profile of ASD individuals and to relate it to behavioural features of the disorder. *Central coherence* is the ability of a person to view and process information as a whole (see Appendix D for a Glossary of terms). Upon initial inspection of an image, typically developing individuals will perceive the image in its entirety, looking at the context as a whole rather than focusing on specific elements of the stimulus and thus often neglecting the finer details of the image. *Weak central coherence* therefore refers to the tendency to process information from a detail-specific perspective, at a local rather than a global level (Brosnan et al., 2004).

Clinical observations suggest that ASD individuals do not focus on the whole image but rather on its finer details, paying attention to specific features of the image and thus exhibiting weak central coherence (Happe & Frith, 2006). This characteristic of information processing in ASD may account for the recorded savant skills in individuals with ASD (e.g., exceptional pitch processing in music; Bonnel at al., 2003).[1]

The WCC theory of cognitive processing and neuropsychological abilities in ASD therefore predicts that children with ASD should, in comparison to typically developing children, show intact and possibly even superior performance on tasks that require a detail-specific approach, with a focus on the individual parts of a structure and not on the structure as a whole. Some data collected from tests that require such local-level focus, such as the Children's Embedded Figures test (CEFT; Witkin, Oltman, Raskin, & Karp, 1971) and the Wechsler Block Design (BD) subtest (Psychological Corporation, 1999), have confirmed this prediction: ASD individuals show intact, and even superior, local-level processing (Baron-Cohen, 2004; Edgin & Pennington, 2005). Other studies (e.g., Burnette et al., 2005) have, however, found that ASD individuals do not perform better on these tasks than typically developing individuals. Therefore, questions remain to be answered in this area of research.

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[1]This superior cognitive ability of autistic individuals on certain tasks is often referred to as their "islets of ability" (Ring et al., 1999).

WCC theory also predicts that ASD individuals should have inferior, or even impaired, performance on tasks that require a global-level focus. This prediction was confirmed by Frith (1997) and Happe (1996), who showed that autistic individuals were less susceptible to certain visual illusions than were typically developing individuals. In the study by Happe (1996) participants had to judge various 2D and 3D visual illusions. The results showed that the ASD participants succumbed to fewer visual illusions than the MR and TD participants. This piece of data suggests that the autistic individuals did not view the visual image from a global level (i.e., they did not appreciate the gestalt of the image), and were thus not affected by the broader context in which the local details were contained.

Ropar and Mitchell (2001) were, however, unable to replicate the findings of Frith (1997); their data suggested that ASD individuals have intact global-level processing. Similarly, Caron et al. (2006) and Rondan and Deruelle (2007) showed that ASD individuals have intact processing at *both* local and global levels, while Caron, Mottron, Rainville, and Chouinard (2004) and Edgin and Pennington (2005) suggested that autistic individuals have only intact (but not superior) abilities on visual-spatial tasks. These recent studies, then, disconfirm both directions of predictions made by WCC theory.

The *Enhanced Perceptual Functioning* model, proposed initially by Mottron and Burack (2001) and revised by Mottron, Dawson, Soulieres, Hubert, and Burack (2006), is used as an alternative framework to the WCC theory to explain perceptual functioning in autism. EPF theory posits that individuals with ASD have superior local-level processing skills *and* superior or intact global-level processing skills.

As support for this theory, Rondan and Deruelle (2007) showed, empirically, that even though individuals with ASD show a bias toward local-level processing, they do not have deficits in global-level processing. In their study, they assessed only HFA and AS adults on two tasks, one assessing global versus local processing and the other assessing configural versus local-level processing. In the first task, participants in both the ASD group and in a matched healthy control group made use of global-level processing efficiently. However, on the second task, ASD participants showed a local-level processing bias that the controls did not. Therefore, the ASD individuals showed a deficit in configural processing (the processing of the spatial relations between elements) rather than a deficit in global-level processing. The ASD individuals were also able shift between global-level processing on the first task to local-level processing on the second task more efficiently than the controls. Overall, then, this study suggests that individuals with ASD have a deficit in configural processing rather than global-level processing. Based on these data, Rondan and Deruelle (2007) suggested that global-level processing is intact in ASD, which is evident from their ability to use this form of processing on tasks which demand such an approach. However, on tasks that do not require a specific approach, ASD individuals may prefer local level processing. Therefore, a local-level processing bias may be related to the demands of the task at hand, rather than indicating a general preference across all tasks.

Deruelle et al. (2006) also provided data supporting the EPF theory. In their study, the clinical participants (children diagnosed with autism and AS) had intact but not impaired global-level processing, and superior local-level processing, in comparison to age-matched healthy controls. The study consisted of two experiments, each using a different spatial task. The first task tested global- versus local-level processing using hierarchical geometrical shapes or letters, and the second tested global- versus local-level processing using face-like geometric patterns. ASD children were able to employ global-level processing on the first task, and shifted to local-level processing for the second task.

Deurelle and colleagues (2006) suggested that a possible explanation for the shift, by ASD children, from global-level processing in Experiment 1 to local-level processing in Experiment 2 was that, for optimal task completion, the former required a global analysis whereas the latter required configural processing (analysis of spatial relationships). The authors suggested that the local bias shown by ASD children in Experiment 2 may therefore be due to either (a) impairment in their configural processing ability, or (b) a preference for local-level processing, even in the presence of intact configural processing ability. Clearly, further research is needed to disentangle these various possibilities. Nonetheless, like Rondan and Deruelle (2007), Deruelle et al. (2006) present data disconfirming the predictions made by the WCC regarding global-level processing in ASD.

In other words, the results of both the above studies suggest that, when individuals with ASD have a choice between local- or global-level processing, they tend to select the former. However, when they need to adopt global-level processing, they can do so quite efficiently. This notion remains open to more empirical testing, however; the inconsistent findings from the studies reviewed above demonstrate a need for further exploration and for further research to pit the two theories against one another, and to thereby help explain the cognitive profile of ASD individuals.

Spatial Navigation in ASD

One particular area of interest for the proposed study is the cognitive domain of spatial navigation. Because spatial navigation is both the culmination of a series of lower-level visual-spatial processing abilities (basic general spatial abilities) and an evolutionarily significant cognitive ability (involving a complicated and well developed mapping device) (O'Keefe & Nadel, 1978), the way in which autistic individuals navigate an environment is an area of ongoing debate (Caron et al. 2004; Daniels, 2009; Edgin & Pennington, 2005).

When navigating within an environment, typically developing individuals can use either a local- and a global-level perspective or both. Certain navigational tasks (e.g., navigating a familiar/known environment) require a local-level focus, whereas others (e.g., navigating a novel environment) require a more global-level focus.

Wayfinding in typically developing individuals. The spatial knowledge of where an object is in order to make use of it or to avoid it is important for every human being (Newcombe, Huttenlocher, Drummey, & Wiley, 1998). Spatial navigation is based around this knowledge. Individuals navigate environments through the use of their perceptions, cognitive maps, or language. Through their own viewing and moving around an environment, individuals collect information about it, which, once encoded, creates a mental representation of that environment (Avraamides, Loomis, Klatzky, & Golledge, 2004; O'Keefe & Nadel, 1978). The information collected is about the configural relations individuals have with the objects within the environment (Mou, McNamara, Valiquette, & Rump, 2004). The mental representation of the environment is a *cognitive map,* a guide and reference system that each individual makes use of when navigating the environment. Cognitive mapping is the "process by which an individual acquires, codes, stores, recalls and decodes information about the relative locations and attributes of the spatial environment" (Caron et al. 2004, p. 468). Unsurprisingly, there are various ways in which information can be encoded to create a cognitive map.

Individuals use a variety of encoding strategies when processing spatial information (Wang, Johnson, Sun, & Zhang, 2005). These strategies enable a person to navigate novel environments. Allocentric and egocentric frames of reference are the two most common types of coding strategies a person may use when navigating an environment. Individuals may choose, depending on the context, which frame of reference to use for a particular navigational task (Wang et al., 2005).

Allocentric referencing is an external-referenced perspective; it pertains to the viewing of an object in relation to external landmarks and to other external objects, and is independent of the relation between the self and that object. By using landmarks as a reference system, allocentric wayfinding allows individuals to move successfully towards target objects or locations from any starting point in the environment (Pentland, Anderson, Dye, & Wood, 2003).

Egocentric referencing, on the other hand, is a viewer-referenced perspective that entails the viewing of an object in relation to the self (Frith & Vignemont, 2005; Newcombe et al., 1998). One form of egocentric spatial coding is response learning. This type of learning involves remembering a planned sequence of actions used to move from a specific starting point to a desired location in an environment (Newcombe & Huttenlocher, 2006).

Both allocentric and egocentric spatial coding can be used if an environment is examined from a fixed viewpoint. Therefore, even when an individual has acquired a representation of an environment through response learning, once her viewpoint has changed, allocentric coding will be required (Burgess, Trinkler, King, Kennedy, & Cipolotti, 2006). Thus, both allocentric and egocentric coding strategies allow an individual to create an image of the environment and to develop a certain type of knowledge about the environment (Roche, Mangaoang, Commins, & Mara, 2005).

Each individual acquires his/her own spatial knowledge through applying the above coding strategies when trying to navigate environments (Thorndyke & Hayes-Roth, 1982). The two main types of knowledge that form part of an individual's cognitive map are survey and route knowledge. Each type of knowledge has its own characteristics, and they differ with regards to the type of tasks to which they are suited to and the aspects of an environment they represent (Caron et al., 2004).

Survey knowledge is acquired through the use of allocentric coding strategies. This form of knowledge is therefore gained from an external perspective (e.g., a physical map of the environment, or an aerial view of it), and it involves information about the global layout of an environment. Survey knowledge therefore looks at objects within the environment from a "general and fixed frame of reference" and does not locate objects through learned routes (Caron et al., 2004, p. 468). This type of knowledge is efficient in helping an individual to find novel routes in an already known environment, or in a novel environment (McNamara & Shelton, 2003). For example, when a previously learned route is unavailable, the general layout of the environment (and, specifically, external landmarks) will be examined to find an alternative route to use in order to reach a desired location.

Route knowledge, on the other hand, is acquired through egocentric coding strategies. This form of knowledge is gained from an internal perspective and involves information about the layout of an environment from the perspective of the individual. In other words, route knowledge is acquired through actually navigating through an environment and not just observing the general global layout. Individuals who use route knowledge usually follow a sequence of actions, a learned response to a route used during navigating (Caron et al., 2004).

In summary, then, route knowledge is applied when a route has been remembered and learnt, whereas survey knowledge provides individuals with a general outline of an environment. Furthermore, the type of knowledge (survey or route) acquired by an individual depends on the type of coding strategy (allocentric or egocentric) used when processing spatial information.

Numerous studies have shown that the hippocampus is likely to be a key component of the neural substrates of allocentric spatial coding (e.g., Abrahams et al., 1997, 1999; Bilkey & Clearwater, 2005). The classic cognitive mapping theory of O'Keefe and Nadel (1978), for instance, proposes that, in humans, the hippocampus of the right cerebral hemisphere plays an important role in developing representations of a place or an object within an environment in relation to external landmarks (allocentric coding strategy) and not in relation to the individual self (egocentric coding strategy). More recently, Burgess, Maguire, Spiers, and O'Keefe (2001), demonstrated in a neuroimaging study that the neural substrates of allocentric spatial coding involve regions spanning the right posterior parietal lobe, right hippocampus and left hippocampus.

Research that has attempted to apply these concepts and findings to ASD, have delivered inconsistent findings. On the one hand, Sparks et al. (2002), Rojas et al. (2004), and Schumann et al. (2004), using structural MRI (sMRI) techniques, found increased hippocampal volume in individuals with ASD when compared to typically developing individuals. This piece of data suggests that allocentric spatial coding (and thus spatial navigation) in individuals with ASD should at least be intact, maybe superior, and definitely should not be impaired. In contrast, however, other sMRI studies have found no difference between the hippocampal volumes of autistic and typically developing individuals (Bigler et al., 2003; Haznedar et al., 2000).

In even further contrast, Nicolson et al. (2006) showed subtle *reductions* in the size of the hippocampus in autistic individuals relative to that in typically developing individuals. That study was the first to make use of computational mapping methods to examine the size of the hippocampus in ASD. In comparison to traditional methods, such as MRI, computational mapping has greater visual and statistical power when examining highly localised subtle abnormalities in subcortical structures such as the hippocampus (Thompson et al., 2004). The data reported by Nicolson et al. (2006) suggest that allocentric spatial coding in individuals with ASD may be impaired.

Taken together, these studies show the need for further examination into possible atypical structure of the hippocampal formation in ASD. Although the current study will not be examining the hippocampal formation directly, it will examine cognitive processes that are purported to be subserved by that brain region, and so will contribute to literature in this regard.

Previous Studies of General Spatial Abilities and Spatial Navigation in ASD

One of the main questions asked in research on spatial cognition in autism, based on the predictions of both the WCC and EPF theories, and on clinical reports of islets of visuospatial strength of autistic individuals, is how the general spatial and spatial navigational abilities of autistic individuals compare, both longitudinally and cross-sectionally, to those of typically developing individuals.[2] Unfortunately, however, there is no clear answer to that question as studies have delivered many inconsistent findings.

Edgin and Pennington (2005) and Daniels (2009) reported, for instance, that HFA individuals, compared to typically developing controls, showed intact, but not superior performance on the Wechsler Block Design subtest, and superior performance on the CEFT. Both studies made use of HFA and AS children; however, the study by Daniels (2009) also included LFA children.

Other studies, in contrast, have shown superior performance by ASD individuals on both the BD subtest and the CEFT (e.g., Jarrold, Gilchrist, & Bender, 2005; Jolliffe & Baron-Cohen, 1997; Mottron, Burack, Iarocci, Belleville, & Enns, 2003; Ropar & Mitchell, 2001; Shah & Frith, 1993). These studies typically made use of HFA and AS individuals, or of only HFA or only AS individuals. Only the study by Shah and Frith (1993) made use of both HFA and LFA individuals. Data reported by Williams, Minshew, and Goldstein (2006) provided further conflicting results: Their study, which used only HFA children as participants, suggested that ASD individuals perform poorly on a specific spatial memory test (the Finger Windows subtest of the Wide Ranging Assessment of Memory and Learning (WRAML; Sheslow & Adams, 1990)) compared to a typically developing control group.

Overall, then, some previously published studies have confirmed predictions made by the WCC and EPF theories, as in those studies ASD individuals showed superior

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[2]The literature on general spatial abilities is closely linked to that on spatial navigation because the performance of individuals on basic spatial tasks (e.g., those that measure spatial perception, visuoconstruction, and visual memory) is critical to spatial navigation: Individuals make use of all those abilities in completing navigation tasks. Therefore, the measures of these general and basic spatial abilities may provide information as to how an individual might perform on spatial navigation tasks.

performance on local-level tasks. Other previously published studies have, however, disconfirmed the predictions made by both theories, as in those studies ASD individuals have shown intact but not superior performance on tasks requiring local-level processing.

With regard to studies specifically focusing on spatial navigation in ASD, findings have generally not confirmed predictions made by the WCC or EFP theories (i.e., for the WCC, ASD individuals should show superior performance on tasks of local-level processing and inferior performance on tasks requiring global-level processing; and for the EPF theory, ASD individuals should show superior performance on tasks of local-level processing and intact performance on tasks requiring global-level processing). Previous studies examining spatial abilities in autism have shown that autistic individuals generally have intact (but not superior) ability to undertake navigation tasks that require local-level focus (Caron et al., 2004; Daniels, 2009).

These findings, of course, are not consistent with the predictions made by WCC theory that autistic individuals will show superior performance on tasks dependent on local-level processing (e.g., navigating in a familiar environment). The other WCC theory prediction, as applied to spatial navigation, states that autistic individuals should show inferior performance on navigational tasks that require global-level processing (e.g., navigating in a novel environment). The study by Daniels (2009) disconfirmed this prediction: the participants in that study showed intact and not inferior performance on a navigation task that required global-level processing.

Following EPF theory, autistic individuals should have superior performance on navigation tasks that require local-level focus and intact, not inferior, performance on navigation tasks that require a global-level focus. As previous findings have shown, ASD individuals have intact but not superior performance on tasks dependent on local level processing, therefore disconfirming the first prediction of the EFP theory. The study by Daniels (2009) confirmed the second prediction of the EPF theory: the ASD participants showed intact performance on the navigation task that required global-level processing.

Although studies examining allocentric and egocentric spatial coding separately have shown that children with ASD have intact egocentric spatial coding but impaired allocentric spatial coding (Daniels, 2009; Pertini, 2004), therefore suggesting that spatial navigation by ASD children in novel environments should be impaired, these suggestions have not been borne out. For instance, Caron et al. (2004), Daniels (2009), and Edgin and Pennington (2005) all found that ASD individuals in their samples had intact spatial navigational abilities. These studies made use of various combinations of ASD individuals. Caron et al.

(2004) included HFA and AS individuals, Daniels (2009) included HFA, AS and LFA individuals, and Pertini (2004) included only AS individuals. Clearly, then, there is the need for further exploration in this area: If ASD individuals have impaired allocentric spatial coding abilities (and perhaps impaired general spatial abilities), then how are they able to perform adequately on spatial navigation tasks?

SPECIFIC AIMS

The current study aimed to produce further data concerning spatial abilities (and particularly spatial navigational abilities) in ASD. More specifically, the study was designed to obtain data on the spatial abilities of LFA individuals; there is a limited amount of information for that group, as most previous studies have used only HFA or only AS, or HFA and AS, individuals.

The inconsistent findings within ASD research regarding spatial navigation raises various questions. This study specifically addressed the following questions, thereby testing predictions made by the WCC and EFP theories:

1. Do children with ASD have intact or superior general spatial abilities in comparison to typically developing individuals?
2. Do children with ASD have intact or impaired allocentric spatial coding?
3. If allocentric spatial coding is impaired in children with ASD (as previous studies suggest), can those children navigate efficiently within a novel environment?
4. Furthermore, if spatial navigation is not impaired, what types of search strategies and reference systems are the ASD individuals using during navigation?

These questions aim to assess the spatial abilities of children with ASD and to better understand which, if any, of the WCC or EPF theories better explains the cognitive abilities of these individuals.

DESIGN AND METHODS

Design

The study was a cross-sectional, quasi-experimental design as it observed participants of different ages at the same time. I compared ASD participants (HFA, LFA, PDD-NOS, and AS children) with typically developing (TD) and mentally retarded (MR) children on a variety of tests assessing different aspects of general spatial ability and spatial navigation.

Participants

One hundred and sixteen children, all between ages 6 and 16 years, were recruited. One group of participants (*n* = 15; the LFA group) consisted of low-functioning autistic children. Following DSM-IV-TR diagnostic criteria, participants in this group had an IQ below 75 with concomitant social, behavioural and intellectual deficits. The second group (*n* = 23; the HFA group) consisted of high-functioning autistic children. Following conventions in the literature, participants in this group had an IQ of higher than 75, and had better adaptive functioning than those in the LFA group. The third group of participants (*n* = 23; the AS group) consisted of children diagnosed with Asperger's syndrome. The fourth group of participants (*n* = 17, the PDD-NOS group) consisted of children diagnosed with pervasive developmental disorder-not-otherwise-specified. All participants in these four groups were volunteers recruited from schools that specialise in teaching autistic children. Prior to being enrolled in the study, all of these participants were independently diagnosed, by appropriately trained clinical psychologists at their schools, as having an autism spectrum disorder.

The other two groups served as controls for the ASD participants. The first of these, and the fifth group (*n* = 16; the MR group) consisted of children formally diagnosed as being mildly mentally retarded. Following DSM-IV-TR criteria, participants in this group had an IQ of between 55 and 70 (see Appendix E) for the full DSM-IV-TR diagnostic criteria for MR). These children were recruited from schools that specialise in teaching MR children within the Western Cape. The sixth group (*n* = 23; the TD group) consisted of typically developing children. All of these children were physically healthy, and had no history of psychoactive medication prescription, head injuries, psychiatric or psychological disorders, or neurological insult. These participants were recruited from local private and public schools.

Across the six groups, participants were matched on sex, age, socio-economic status and home language. Participants were only included if they were able to speak English or Afrikaans fluently, as the tasks used during the assessment were administered in either

English or Afrikaans. Participants with any sensory impairments or medical problems that may have affected their ability to complete the various tasks were also excluded from the sample.

General Measures

Parents/guardians of participants were asked to complete a demographic questionnaire before the assessment took place (see Appendix F). This questionnaire was designed to obtain information, such as the participant's age, sex, socioeconomic status, date of birth and other information about the participant's life that might be used as the basis for covariate data analyses. The questionnaire also provided information regarding the participant's mental and physical wellbeing that was used to establish whether the participants should be excluded based on the eligibility criteria listed above. The amount of time spent using a computer was also recorded as previous research has shown that computer use may facilitate spatial performance (Subrahmanyam & Greenfield, 1994).

Participants were administered a test of general intellectual functioning and several tests of various spatial abilities. This battery of tests, which includes both computer-based and pencil-and-paper instruments, is presented in Table 1.

The *Wechsler Abbreviated Scale of Intelligence* (WASI; Psychological Corporation, 1999) was used to test the participants' intellectual functioning. It is a robust and standardised battery, featuring these four subtests: Vocabulary, Similarities, Block Design (BD), and Matrix Reasoning. The Verbal IQ (VIQ) of participants is measured using the combined scores of the Similarities and Vocabulary subsets, while Performance IQ (PIQ) is measured using the combined scores of the Block Design and Matrix Reasoning subsets.

In this study, PIQ was used as a proxy for general intellectual functioning due to the fact that poor language ability is often present in ASD, and so including VIQ in the estimate of general intellectual functioning would probably have introduced a large margin of error. With regard to the two subtests that comprise the PIQ measure, the BD subtest required the participant to build specific patterns using coloured blocks. Each block has a white side, a red side, and a half red and half white side. The participants were required to create the same pattern created by the examiner with their own blocks, or to create a pattern shown in a stimulus booklet. The Matrix Reasoning subtest required the participant to select the correct option from an array of pictures, and to thereby complete a pattern shown in the stimulus booklet.

The BD subtest was also used as a separate measure of visual-spatial ability. Autistic individuals have been reported, in previous studies, to have superior abilities on the BD test (e.g., Caron et al., 2004). Other studies, to the contrary, have shown that autistic individuals have intact but not superior abilities on this test.

Table 1
Tests Used in the Current Study

Test Name	Domain Tested	Autism Study in Which Test was Used
WASI	General intellectual functioning	Daniels (2009)
ROCF	Visual memory, visual spatial ability, visuoconstructional ability	Schoolz et al. (2006)
CEFT	Central coherence, local processing vs. global processing	Jolliffe & Baron-Cohen (1997)
NBMT-CV	Non-verbal spatial processing and orientation	Pentland et al. (2003)
SPC	Allocentric spatial coding	Pertini (2004)
SRL	Egocentric spatial coding	Pertini (2004)
CG Arena	Spatial navigation	Edgin & Pennington (2005)

Note. WASI = Wechsler Abbreviated Scale of Intelligence; ROCF = Rey-Osterrieth Complex Figure test; CEFT = Children's Embedded Figures Test; NBMT-CV = Nine Box Maze Test - Children's Version; SPC = Spatial Place Coding test; SRL = Spatial Response Learning test; CG Arena = Computer-Generated Arena.

Measures of General Spatial Ability

The *Rey-Osterrieth Complex Figure* (ROCF; Rey, 1941) is a standardized measure of visual memory and visuo-constructional ability. This test has been used in numerous clinical research studies of ASD (e.g., Happe & Frith, 2006). The ROCF requires the participant to copy a two-dimensional image displayed on a card in front of him. Once the copy is made, the card is removed from the participant's view. After a 3-minute filled delay, the participant is asked to re-draw the figure from memory. After a 30-minute filled delay, the participant is again asked to re-draw the image from memory. The raw scores obtained for each of the drawings were used for the analysis of this task.

The *Children's Embedded Figures Test* (*CEFT;* Witkin, Oltman, Raskin, & Karp, 1971) was used to test central coherence. The test requires the participant to find a familiar object (usually a triangle or house) that has been embedded within a complex design. After a few practice trials, the participant is shown 25 complex designs, one after the other, and is asked to give a description of the design. This portion of the task is designed to help the participant encode the design. After the participant has identified the design, he/she is asked to try and locate the hidden object (triangle and house) within the complex picture.

The outcome measures for the CEFT are derived in this way: If the participant is able to identify the hidden object freely without needing to make use of the actual object, he/she is awarded 1 point. After three consecutive scores of 0 points (i.e., three consecutive trials on which the participant is not able to identify the hidden object), the participant is shown the actual object to see whether this helps him/her locate the hidden object. If the participant is able to locate the object using the cut-out, the latter is then removed from the participant's sight for the following trial. Participants are also not awarded a point if the cut-out is used or is asked for by the participants to use when trying to find the hidden object. After five consecutive scores of zero, the task is discontinued.

Empirical studies (e.g., Jolliffe & Baron-Cohen, 1997) have shown that participants make use of local-level processing when identifying an object within a complex figure, thus making this test a good assessment of the presence of weak central coherence. Studies have also shown that autistic individuals perform better than typically developing individuals on the CEFT and other tests that encourage the use of local-level processing (see, e.g., Edgin & Pennington, 2005; Ropar & Mitchell, 2001).

Measures of Allocentric Spatial Ability

The *Nine Box Maze Test – Child Version* (*NBMT-CV*; Pentland et al., 2003) was created to ensure that certain aspects of the original NBMT (Abrahams, Pickering, Polkey & Morris, 1997), such as the vocabulary, style and length, were suitable for children. This test is based on the cognitive mapping theory of hippocampal function and is a test of the purported allocentric spatial coding abilities of the right hemisphere hippocampus. In essence, therefore, the test measures the ability of participants to locate objects by relating them to other objects, and not to themselves, thereby assessing the participant's allocentric spatial coding ability.

This test consisted of three stages. The first stage was the Object Familiarisation stage, the second was the Five Box Maze Test and the last stage was the Nine Box Maze Test. The Object Familiarisation stage began with the examiner showing 10 common objects (e.g., toy car, spoon, apple, lollipop, etc.) to the participant, ensuring that the participant was aware of what each object was (see Figure 1). The items were presented to the participant in a fixed order. After a 1-minute delay, the participant was asked to recall as many objects as possible. One point was awarded if the participant was able to correctly recall an object. If any participant in the ASD group was non-verbal, he/she was asked to select (from a card containing pictures of each object shown, as well as some pictures of objects that were not shown) which objects were shown.

The Five Box Maze Test stage followed immediately after the Object Familiarisation stage. This stage involved placing five containers at equal distances from each other in front of the participant. The participant was clearly shown that two of the objects that were introduced earlier were placed into two of the containers. The participant was then moved to a different position at the table and asked to identify which objects had been hidden. If the participant could correctly recall which objects were hidden, four points were awarded (two per object). If the participant was unable to recall one or both of the previously hidden objects, he/she was shown a booklet containing pictures of all the objects and asked to select which were hidden. The child was awarded one point per object successfully recognized. If the child was unable to either recall or recognize the previously hidden objects, no points were awarded. The participant was then asked to identify which containers had been used. Two points (one point per container) were awarded for correctly recalling which containers were used. Lastly, the participant was asked to identify which objects were hidden in which containers. Each correct association was worth one point.

If the participant obtained a perfect score (8 points), he/she proceeded immediately to the Nine Box Maze stage. If the participant did not obtain a perfect score on the first Five Box Maze Test trial, more trials (up to a maximum of two trials) were conducted using the same procedure. If the participant was still not able to obtain a perfect score, he/she was not asked to proceed any further with this test.

The Nine Box Maze Test stage followed immediately after the Five Box Maze Test stage. The participant was given the same instructions as during the Five Box Maze Test, except that nine containers were used and four objects were hidden. Four trials were completed regardless of whether the objects and containers were recognised or whether a connection between the two was made. During each trial, two of the objects remained in the same location, whereas the other two objects and locations were changed. At the end of the task, the participant was asked about the strategies used to help find the hidden objects (Pertini, 2004).

The *Spatial Place Coding Task* (*SPC*; Pertini, 2004) was used to measure spatial processes and strategies used by participants, specifically the participant’s ability to use fine-grained allocentric spatial coding strategy. This task involved examining an object on a white piece of paper for approximately 5 seconds and remembering the object’s position. The cardboard was then moved to a different location while the participant turned around, facing away from the paper. The participant was then asked to turn around and face the cardboard and to place the object in the same position the experimenter had placed it earlier. The location of both the cardboard and the object were predetermined by the researcher. The object was placed in one of the eight positions equally distanced from each other on the midline of the cardboard. Each time the cardboard was moved, it was moved either 20cm to the left or right of its original position. This procedure was administered 24 times (Pertini, 2004). The mean distance (in mm) between the location in which the participant placed the object and the right hand side of the cardboard was used to derive a score for the participant.

Figure 1. NBMT-CV apparatus.

Measure of Egocentric Spatial Ability

The *Spatial Response Learning Task* (*SRL*; Pertini, 2004) was used to assess the ability of participants to use egocentric rather than allocentric spatial coding. The same materials and generally the same procedures used in the SPC were also used in the SRL. In this task, however, the participant was given an object to hold in his/her hand and was told to close his/her eyes. The latter instruction was given so as to ensure that no external landmarks or cues were used to find the location of the object on the cardboard. While the participant's eyes were closed, the experimenter guided the participant's hand (with the object in it) to a specific location on the cardboard. The participant was instructed to hold his/her hand over the cardboard for 3 seconds. He/She was then asked to move his/her hand back to his/her side, count to three, and then move the hand back to the same position on the cardboard on which the experimenter had placed it. The participant therefore needed to make use of bodily cues, rather than external cues, when finding the location. This procedure was administered eight times. The eight predetermined positions were recorded (in mm) by the researcher; these were the true object positions. The participant's score was the distance (in mm) from the right hand side of the cardboard to the position of the replaced figure.

Measures of Spatial Navigation

The *Computer-Generated Arena* (CG Arena; Jacobs, Thomas, Laurance & Nadel, 1998; Thomas et al., 2001) is a virtual reality spatial navigation task. The virtual environment (VE) used in this task was projected onto a conventional desktop or notebook computer monitor. The environment consisted of a circular arena within a square room with pictures on each of the walls (see Figure 2). The pictures were distal cues that helped the participants form a cognitive map of the CG Arena. The aim of the task was to locate a square platform that was on the floor of the room. This platform was visible for the first few trials (visible target trails) and was then removed for the next several trials (invisible target trials).

In the visible target trials, participants were simply required to locate the platform and move towards it. This set of trials provided the participants with practice at moving a joystick to navigate within the VE, and introduced them to the components of the VE and the task requirements.

The invisible target trials commenced once the visible target trials had been completed successfully. On the invisible target trials, participants were required to locate the same platform; this time, however, the platform was hidden below the floor until the participant stepped onto it. The platform became visible once the participant had located it. The invisible target was always in the same position on all of the trials. Therefore, the object of the invisible target trials was to locate and remember where the invisible target was as quickly as possible; successful performance thus required the formation of a cognitive map of the arena.

The final trial was the probe trial. On this trial the target was, unbeknown to the participant, removed from the arena. This trial provided an indication as to how well the participant remembered the location of the target, and whether he/she was locating it by luck (e.g., by simply circling the room until running into it) or intentionally. Once time expired on the probe trial, the CG Arena testing session concluded and the participant was presented with a black screen to indicate the task was completed (Thomas et al., 2001).

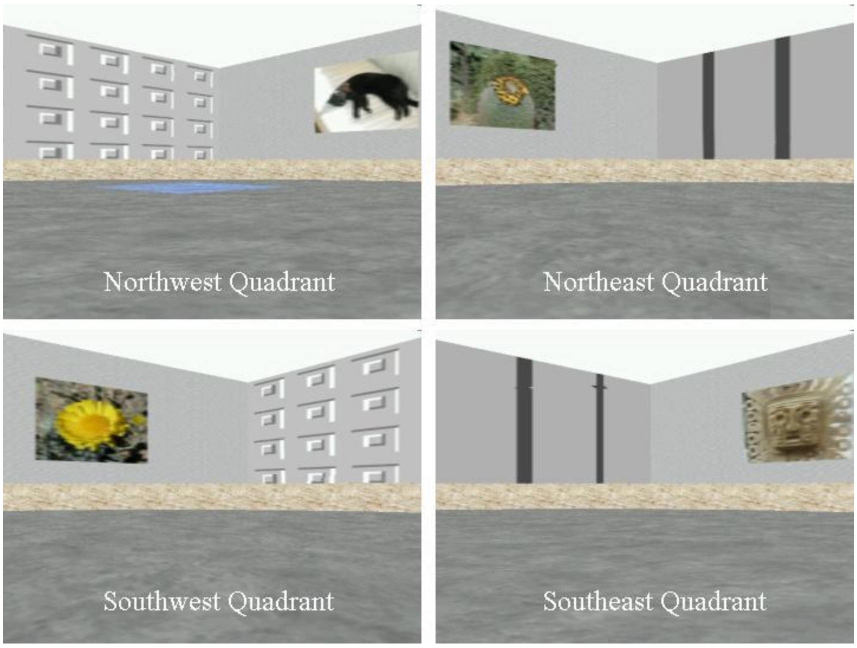


Figure 2. Four views from within the experimental room of the CG Arena. The target towards which participants had to navigate in the visible trials condition is represented as a blue square in the upper left panel of the figure.

Once the computer task was completed, the participants were asked to complete two tests related to the CG Arena: the Object Recognition Task (ORT) and the Arena Reconstitution task (ART). In the ORT, the participants were asked to identify which pictures they remembered being present in the CG Arena. A stimulus card containing all eight pictures present on the Arena walls, as well as eight pictures that were not present in the Arena, were shown to the participants (see Figure 3). The experimenter then proceeded to ask the participant to identify which pictures were present and recorded the number of correctly and incorrectly identified pictures. This task measured the participant's non-spatial recognition memory.

The ART, in contrast, was a test of the participant's spatial memory and assessed the quality of his/her cognitive map of the CG Arena. Participants were given an image of a topographic view of the computer-generated room with no details or cues present (see Figure

4). They were then given icons representing the eight pictures that appeared on the walls of the Arena, and were asked to place those icons in the locations in which they appeared during the invisible target trials. The participants were also asked to identify, using the four squares on the stimulus sheet, the location of the target relative to the positions of the icons they had placed.

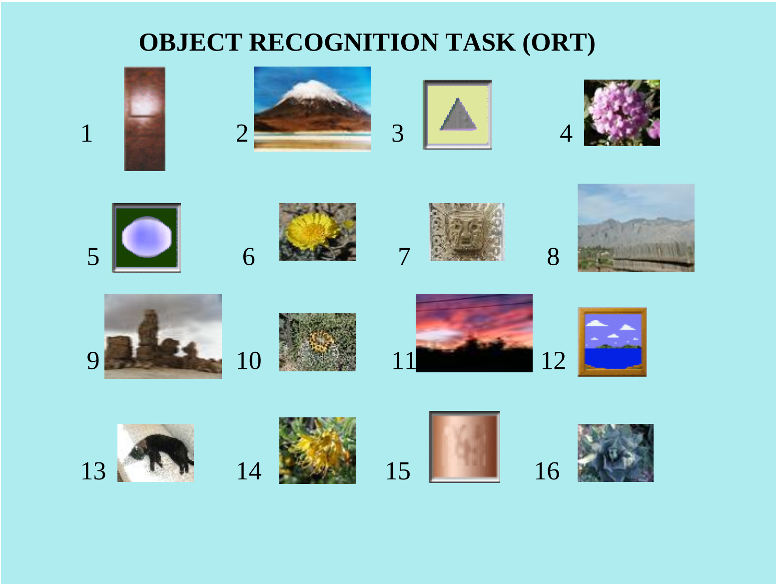
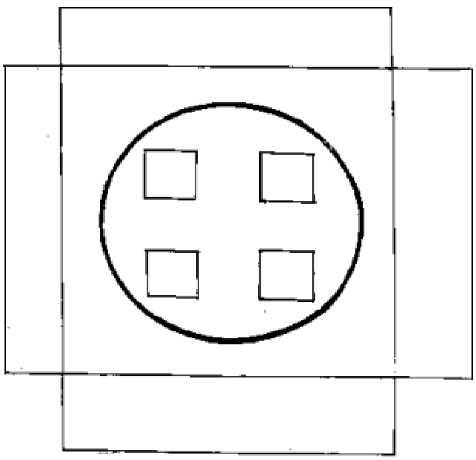


Figure 3. Object Recognition Task (ORT) stimulus sheet. Participants needed to decide whether each of the items shown on the sheet was present in the CG Arena experimental room.



ARENA RECONSTITUTION TASK (ART)

Figure 4. Arena Reconstitution Task (ART) stimulus sheet.

Procedure

Before testing began, written consent was obtained from the parent/guardian of each participant (see Appendix G). Demographic questionnaires were also filled in by the parents or guardians before testing so as to ensure that all participants met the inclusion criteria. At the beginning of each test session, each participant who was capable thereof, signed an assent form (see Appendix H).

The tests listed above were completed over two sessions, with each session lasting between 40 and 90 minutes. Some sessions were shorter depending on the concentration span of the child. All the tests were administered according to conventional procedures outlined in the literature and in the various test manuals. If the participant became fatigued during the session, he/she was given the opportunity to take a break.

The first session included the WASI Performance subtests, the ROCF, and the CG Arena. The second session included the CEFT, SRL, SPC, and NBMT-CV. Testing took place at the participant's school or home or in a research laboratory at the Department of Psychology at UCT, depending on which was more convenient for the participant.

Statistical Analysis

An alpha level of $p = 0.05$ was used in all decisions regarding statistical significance. Eta-squared effect size estimates were reported for all analyses.

Descriptive statistics. The first stage of data analysis involved examination of descriptive statistics. This stage of the analysis allowed for (a) derivation of measures of central tendency and of variation, (b) description of the distribution of the various dependent variables (i.e., scores on the various cognitive tests), (c) detection of outliers, and (d) determination whether the assumptions underlying subsequent inferential analyses were met.

Analysis of data from general measures. One-way analysis of variance (ANOVA) was used to determine if there were any between-group differences on continuous demographic and intelligence variables (e.g., age and PIQ). Similarly, chi-squared analysis was conducted on categorical variables (e.g., sex, handedness, computer use) to determine if there were any statistically significant group differences.

WASI. The WASI was scored according to the conventional procedures outlined in the accompanying test manual (Psychological Corporation, 1999) to determine a measure of PIQ.

Analysis of data from measures of general spatial ability. Between-group differences on the scores for tests measuring general spatial ability (ROCF, CEFT, BD) were analysed using one-way ANOVA.

ROCF. The ROCF scoring system used in the present study was that of Taylor (1959), as outlined in Lezak, Howieson, and Loring (2004, p. 542). This 36-point scoring system measured how accurately an individual was able to copy and recall the figure. Within this scoring system, 18 details of the figure were used to score the participant's drawings. The participant was awarded 2 points if the details were correctly drawn and placed; points were taken away for incomplete or incorrectly placed details. Thus, the copy score measured the participant's visuo-constructional abilities, while the immediate and delayed recall scores measured both visuo-constructional and visual memory abilities.

CEFT. The total number times the participant correctly identified the embedded figure within the complex design was recorded and used as the CEFT score. This score provided a measure of local-level processing.

BD. The participant's age-adjusted scaled scores on the BD subset were derived by converting the raw scores using the conversion tables in the administration manual of the WASI (Psychological Corporation, 1999). Higher scaled scores indicated a greater aptitude for visuo-spatial construction.

Analysis of data from measures of allocentric spatial coding ability.

NBMT-CV. Each stage of the test procedure produced different outcome variables. In the Object Familiarisation stage, the score for each participant was the number of freely recalled objects after 1 minute. On the Five Box Maze Test, participants received a score out of 24, and if they progressed to the Nine Box Maze Test, participants received a score out of 32. Separate one-way ANOVAs were conducted to examine possible group differences on these three outcome variables.

SPC. The SPC task was used to test the participant's allocentric spatial ability. In this task, there were eight evenly spaced (by 89mm) predetermined locations along the midline of the cardboard. These were the true object positions. Hence, the first true object location was 89mm from the right hand side of the cardboard, the second true object location was 179mm from the right hand side of the cardboard, and so on, continuing to the eighth true object location (712mm; Pertini, 2004). The distance (in mm) between the location at which the participant placed the object and the right hand side of the cardboard was used to derive a response location score for the participant on each of the 24 coding trials. Three response location scores were obtained for each participant at each of the eight intervals. The participants' responses for each location were averaged to produce a mean response location.

Following Pertini (2004) and Daniels (2009), the mean response error score for each participant was calculated. This score was calculated by subtracting the participant's response locations (in mm) from the true object location. Therefore, positive errors showed a bias to the right of the true object location, whereas negative errors showed a bias to the left of the true object location. A repeated-measures ANOVA was used to examine the effect of the true object location on the mean response error score for each group.

Analysis of data from measures of egocentric spatial coding ability.

SRL. The SRL task was used to test the participant's egocentric spatial ability. In this task, there were eight evenly spaced (by 89mm) predetermined locations along the midline of the cardboard. These were the true object positions. Hence, the first true object location was 89mm from the right hand side of the cardboard, the second true object location was 179mm from the right hand side of the cardboard, and so on, continuing to the eighth true object location (712mm; Pertini, 2004). The participant's response location score was the distance (in mm) from the right hand side of the cardboard to the position of the replaced figure on each of the 8 trials.

Following Pertini (2004) and Daniels (2009), the mean response error score for each participant was calculated. This score was calculated by subtracting the participant's response locations (in mm) from the true object location. Therefore, positive errors showed a bias to the right of the true object location, whereas negative errors showed a bias to the left of the true object location. Repeated-measures ANOVA was used to examine the effect of the true object location on the mean response error score for each group.

Analysis of data from measures of spatial navigation. The CG Arena software produces an output file that allows for the examination of the participant's performance on the CG Arena. This output file provides information regarding the participant's path length to the target, the number of times the participant was able to locate the hidden target, and the amount of time spent looking for the target in the correct quadrant.

CG Arena visible trials. These trials measured the participant's egocentrically-based navigational ability. One-way ANOVA were used to examine group differences with regard to average path length across the four visible target trials.

CG Arena invisible trials. The first analysis of data from the invisible target trials focused on the number of times the participants successfully located the target across the trials. One-way ANOVA was used to examine the group differences with regard to this outcome variable.

The next analysis of data from the invisible target trials focused on the path length participants took to go from their starting position to the target on each of those trials. A repeated-measures ANOVA was used to examine within-group change, and between-group differences, across this set of trials.

CG Arena probe trial. The percentage of the total time spent searching for the invisible target in the correct quadrant during the probe trial was examined next. This score provided an indication as to whether the participants accurately remembered where the target was during the set of invisible target trials. One-way ANOVA was used to examine the group differences with regard to this outcome variable.

CG Arena search strategies. The kinds of search strategies used by the participants on the invisible target trials were examined and classified using a taxonomy described by Kallai, Makany, Karadi, and Jacobs (2005). More specifically, the participants' search paths across all five invisible target trials were classified as being predominantly one of these strategies: Thigmotaxis, Circle, Visual Scan, or Enfilading. The *Thigmotaxis* strategy is defined by the participant following a circular path close to the wall of the arena. The *Circle* strategy is defined by the participant following an arch-shaped path that occurs inside the arena but does not involve the use of the wall. The *Visual Scan* strategy is used when an individual stands in a fixed position and turns around to examine the arena's distal cues. The *Enfilading* strategy involves small position corrections and non-strategic motions. Chi-squared tests were used to examine whether there were any associations between group membership and type of strategy used.

ORT. To score the ORT, a d-prime (*d'*) score was derived for each participant. D-prime is commonly used as a measure of sensitivity in signal detection theories, as it represents the difference between the means of the Signal Present and Signal Absent distributions. To calculate *d'* for each participant, the participant's hit (H) and false alarm (FA) rates was entered into a the formula $d' = z(\text{FA}) - z(\text{H})$. A large absolute value of *d'* indicated that a person is more sensitive to the difference between the Signal Present and Signal Absent distribution, whereas values of *d'* that are small and near zero indicated chance performance (See http://wise.cgu.edu/sdtmod/signal_applet.asp for more details.). One-way ANOVA was used to examine group differences with regard to this outcome variable.

ART. For each of the eight pictures on the ART stimulus sheet, an individual displacement score was calculated. This score was formulated by calculating the number of places between a picture's true location and the participant's placement of that picture. Individual displacement scores were then totalled to form a total displacement score. High displacement scores indicated poor reconstructions, whereas low displacement scores indicated better reconstructions. One-way ANOVA was used to examine group differences with regard to this outcome variable.

RESULTS

The major inferential analyses of continuous data involved between-group comparisons to assess the differences between the HFA, PDD-NOS, AS, and TD individuals, and between the LFA and MR individuals, on the various cognitive tests. In this regard, two separate analyses were done to ensure that the participants were compared only with their specific matched control group. Chi-squared analyses of the categorical data sought to establish whether there were statistically significant between-group differences in the category frequencies on those variables. Certain tasks had data missing due to researcher error; on those tasks, the analyses were simply completed with smaller sample sizes.

Most measures were analysed using ANOVA. For most of the outcome variables, all the assumptions underlying this test were met. In some cases, Levene's test for homogeneity of variance was statistically significant, but all other assumptions were upheld and therefore the analysis proceeded conventionally as ANOVA is robust.

This section of the thesis will be laid out in the following manner: First, I will discuss analyses s of the measures of sociodemographic characteristics and general intellectual functioning of the sample. Second, I will discuss analyses of between-group differences on measures of (1) general spatial ability, (2) allocentric spatial coding, (3) egocentric spatial coding, and (4) spatial navigation. For each of the outcome measures, the effect of PIQ on the tasks will be discussed, and a summary of the results will be given.

Measures of Sociodemographic Characteristics and General Intellectual Functioning

Table 2 presents demographic information for the six groups of participants. There is some missing demographic data due to confidentiality issues (i.e., some participants were reluctant to reveal total income for the year, or highest level of education of either parent) or to incomplete form completion by the parents of the participants. For the continuous variables listed in that table (age and WASI PIQ), one-way ANOVAs sought to determine if there were any statistically significant between-group differences. For the reasons noted above, I conducted two separate comparisons: First, I compared the LFA and MR groups to one another, and then I compared the HFA, AS, PDD-NOS, and TD groups to each other.

Table 2

Demographic Characteristics of the Current Sample

Variable	LFA (*n* = 15)	MR (*n* = 16)	AS (*n* = 23)	PDD-NOS (*n* = 17)	HFA (*n* = 23)	TD (*n* = 23)
Age (years:months)	11.27 (5.93)	10.56 (4.00)	11.09 (6.45)	9.24 (5.25)	9.22 (5.78)	10.04 (6.13)
Race (White:Black:Coloured:Indian)	6:4:3:1:1	0:5:11:0:0	21:0:1:1:0	14:0:3:0:0	10:6:5:1:1	11:2:9:1:0
Sex (male:female)	12:3	12:4	22:1	13:4	19:4	15:8
Home language (Eng:Afr:Eng/Afrik:Xh/Zul:Missing)	10:2:0:3:0	7:2:2:5:0	20:2:0:0:1	17:0:0:0:0	16:1:1:5:0	13:8:0:2:0
Handedness (left:right:ambidextrous:missing)	1:12:2:0	2:13:1	5:16:1:1	0:16:1:0	1:18:0:3	0:22:0:1
SES (low:medium:high:missing)	4:4:5:2	12:1:1:2	3:9:8:3	9:1:4:2	10:4:4:5	9:8:5:1
Computer use (Frequently;Sometimes:Never:Missing)	8:3:2:2	5:2:7:2	19:1:0:3	12:2:0:3	10:4:1:8	13:4:1:5
WASI PIQ	65.73 (5.06)	66.18 (4.31)	94.87 (16.15)	89.12 (12.28)	88.70 (8.44)	98.57 (15.28)

Note. LFA = low-functioning autism; MR = mentally handicapped; HFA = high-functioning autism; AS = Asperger's syndrome; PDD-NOS = pervasive developmental disorder, not otherwise specified; TD = typically developing; SES = socioeconomic status; WASI PIQ = Wechsler Abbreviated Scale of Intelligence Performance IQ. For Age and PIQ, means are presented with standard deviations in parentheses.

With regard to *age*, there were no statistically significant between-group differences for the LFA versus MR comparison, $F(1, 29) = 1.295$, $p = .264$, $\eta^2 = .04$. There was a statistically significant between-group difference on the four-group analysis, however, $F(3, 82) = 2.827$, $p = .044$, $\eta^2 = .09$. Tukey's HSD post-hoc analysis showed, though, there was no significant difference between the HFA, AS, and PDD-NOS groups when compared with their IQ matched control group (TD).

With regard to *PIQ*, there were no statistically significant between-group differences for the LFA versus MR comparison, $F(1, 29) = 0.073$, $p = .789$, $\eta^2 = .002$. There was a statistically significant between-group difference on the four-group analysis, however, $F(3, 80) = 4.518$, $p = .005$, $\eta^2 = .14$. Tukey's HSD post-hoc analysis showed there was a significant difference between the HFA and TD group and between the PDD-NOS and TD group.

For the categorical variables listed in Table 2 (race, sex, home language, handedness, SES, and computer use), chi-squared analyses sought to determine if there were any statistically significant between-group differences. Again, I conducted two separate comparisons: the HFA, AS, PDD-NOS, and TD groups against one another, and then the LFA and MR groups against each other.

The first set of analyses showed that there were statistically significant differences between the HFA, AS, PDD-NOS, and TD groups in terms of race distribution, $\chi^2(12, N = 86) = 29.44$, $p = .003$; home language distribution, $\chi^2(18, N = 86) = 33.50$, $p = .014$; and handedness distribution, $\chi^2(9, N = 85) = 22.93$, $p = .006$. There was no statistically significant difference between these groups in terms of male-female distribution, $\chi^2(3, N = 86) = 7.76$, $p = .051$; computer use, $\chi^2(9, N = 86) = 10.66$, $p = .299$; and SES, $\chi^2(9, N = 83) = 14.33$, $p = .111$.

The second set of analyses showed that there was a statistically significant difference between the LFA and MR groups in terms of race distribution, $\chi^2(4, N = 31) = 16.03$, $p = .002$. There were no statistically significant differences between these two groups in terms of home language distribution, $\chi^2(6, N = 31) = 6.72$, $p = .347$; handedness distribution, $\chi^2(3, N = 31) = 4.51$, $p = .211$; male-female distribution, $\chi^2(1, N = 31) = 0.111$, $p = .739$; computer use $\chi^2(9, N = 31) = 3.81$, $p = .283$; and SES, $\chi^2(3, N = 31) = 8.44$, $p = .038$.

Based on the above results, no ANCOVAs with age, sex, computer use, or SES as covariates were conducted as there were no statistically significant between-group differences on these variables. Due to the statistically significant difference in terms of PIQ between the HFA, AS, PDD-NOS and TD groups, analysis of covariance (ANCOVA), with PIQ as the covariate, was used to analyse the data from tasks where there was a significant difference between these groups.

Research on race in ASD has shown that race has no effect of cognitive functioning in ASD, and therefore no ANCOVA with race as a covariate was conducted. Even though there was a significant difference in home language between the groups, all the participants attended schools that used either English or Afrikaans as the medium of instruction, and therefore all participants were able to understand complex instructions. (As noted in the Methods section, potential participants who were unable to understand test instructions were excluded from the study). Therefore no ANCOVA with home language as the covariate was conducted. With regard to handedness, no ANCOVA was conducted as handedness does not typically matter in the completion of the tasks in this study.

Measures of General Spatial Ability

Tables 3 and 4 shows the results of two one-way ANOVAs; the first, shown in Table 3, compared the performance of participants in the LFA and MR groups to one another on measures of general spatial ability (specifically, the ROCF, CEFT, and Block Design tasks), while the second, shown in Table 4, compared the performance of participants in the HFA, AS, PDD-NOS, and TD groups on the same measures.

Table 3

Measures of General Spatial Ability: ANOVA results LFA and MR groups

Variable	*M* (*SD*)	*df*	*F*	*p*	η^2
ROCF	9.16 (9.8)	1	0.01	.931	< .001
CEFT	4.97 (3.85)	1	3.19	.084	.10
BD	30.65 (4.12)	1	2.10	.158	.07

Note. LFA = low-functioning autism (*n* = 15); MR = mentally retarded (*n* = 16); ROCF = Rey-Osterrieth Complex Figure; CEFT = Children's Embedded Figures Test; BD = Block Design subtest of the WASI.

Table 4

Measures of General Spatial Ability: ANOVA results AS, PDD-NOS, HFA and TD groups

Variable	*M* (*SD*)	*df*	*F*	*p*	η^2
ROCF	17.95 (10.73)	3	6.35	< .001***	.19
CEFT	13.63 (6.60)	3	8.88	< .001***	.25
BD	47.60 (10.57)	3	3.28	.025*	.11

Note. HFA = high-functioning autism (*n* = 23); AS = Asperger's syndrome (*n* = 23); PDD-NOS = pervasive developmental disorder not-otherwise specified (*n* = 17); TD = typically developing (*n* = 23); ROCF = Rey-Osterrieth complex figure; CEFT = Children's Embedded Figures Test; BD = block design subtest of the WASI.

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

With regard to performance on the ROCF test, there was no statistically significant difference between the LFA and MR groups. There was, however, a statistically significant difference in performance between the HFA, AS, PDD-NOS, and TD groups on this task (see Figure 5). The effect size estimate shown in Table 4 indicates that 19% of the variance in ROCF performance across the latter four groups is explained by group membership. Tukey's Honest Significant Difference (HSD) post-hoc analysis (see Table 5) showed there were statistically significant differences in ROCF performance between the HFA and TD groups, between the HFA and AS groups, and between the PDD-NOS and TD groups. Both the HFA and PDD-NOS groups performed significantly more poorly than the TD group.

Table 5

Measures of General Spatial Ability: Post-hoc analysis ROCF

	Group						
	LFA	MR	AS	PDD-NOS	HFA	TD	
Pairwise Comparison #	(*n* = 15)	(*n* = 16)	(*n* = 23)	(*n* = 17)	(*n* = 23)	(*n* = 23)	*p*
1	9.00 (10.34)	9.31 (9.66)	------	------	------	------	.931
2	------	------	------	------	12.45 (8.80)	23.17 (9.52)	.003**
3	------	------	21.27 (9.81)	------	12.45 (8.80)	------	.020*
4	------	------	------	13.71 (11.41)	12.45 (8.80)	------	.979
5	------	------	21.27 (9.81)	------	------	23.17 (9.52)	.915
6	------	------	21.27 (9.81)	13.71 (11.41)	------	------	.089
7	------	------	------	13.71 (11.41)	------	23.17 (9.52)	.018*

Note. Means are presented with standard deviations in parentheses. LFA = low-functioning autism; MR = mentally retarded; HFA = high-functioning autism; AS = Asperger's syndrome; PDD-NOS = pervasive developmental disorder not-otherwise specified; TD = typically developing; ROCF = Rey-Osterrieth Complex Figure test.

*$p < .05$. **$p < .01$.

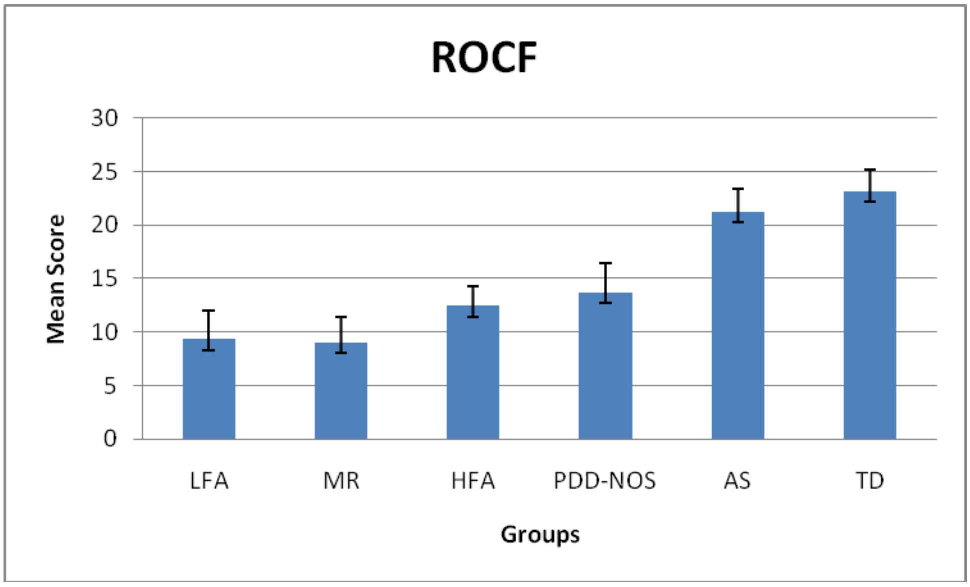


Figure 5. Performance by all groups on the ROCF test. The error bars indicate the standard error of means.

With regard to performance on the CEFT, there was no statistically significant difference between the LFA and MR groups. There was, however, a statistically significant difference in performance between the HFA, AS, PDD-NOS, and TD groups on this task (see Figure 6). The effect size estimate shown in Table 4 indicates that 25% of the variance in CEFT performance across these four groups is explained by group membership. Tukey's HSD post-hoc analysis (see Table 6) showed there was a statistically significant difference in CEFT performance between the HFA and TD group, between the HFA and AS group, between the PDD-NOS and TD group, and between the PDD-NOS and AS group. Both the HFA and PDD-NOS groups performed significantly more poorly than the TD and AS groups. There were no statistically significant differences in performance between the HFA and PDD-NOS groups, and between the AS and the TD groups.

Table 6

Measures of General Spatial Ability: Post-hoc analysis CEFT

	Group						
Pairwise Comparison #	LFA (*n* = 15)	MR (*n* = 16)	AS (*n* = 23)	PDD-NOS (*n* = 17)	HFA (*n* = 23)	TD (*n* = 23)	*p*
1	6.20 (4.71)	3.81 (2.46)	------	------	------	-----	.084
2	------	------	------	------	10.14 (5.81)	17.17 (6.04)	< .001***
3	------	------	16.09 (5.90)	------	10.14 (5.81)	------	.006**
4	------	------	------	10.18 (5.49)	10.14 (5.81)	------	.999
5	------	------	16.09 (5.90)	------	------	17.17 (6.04)	.925
6	------	------	16.09 (5.90)	10.18 (5.49)	------	------	.013*
7	------	------	------	10.18 (5.49)	------	17.17 (6.04)	.002**

Note. Means are presented with standard deviations in parentheses. LFA = low-functioning autism; MR = mentally retarded; HFA = high-functioning autism; AS = Asperger's syndrome; PDD-NOS = pervasive developmental disorder not-otherwise specified; TD = typically developing; CEFT = Children's Embedded Figures Test.

* $p < .05$. ** $p < .01$. *** $p < .001$.

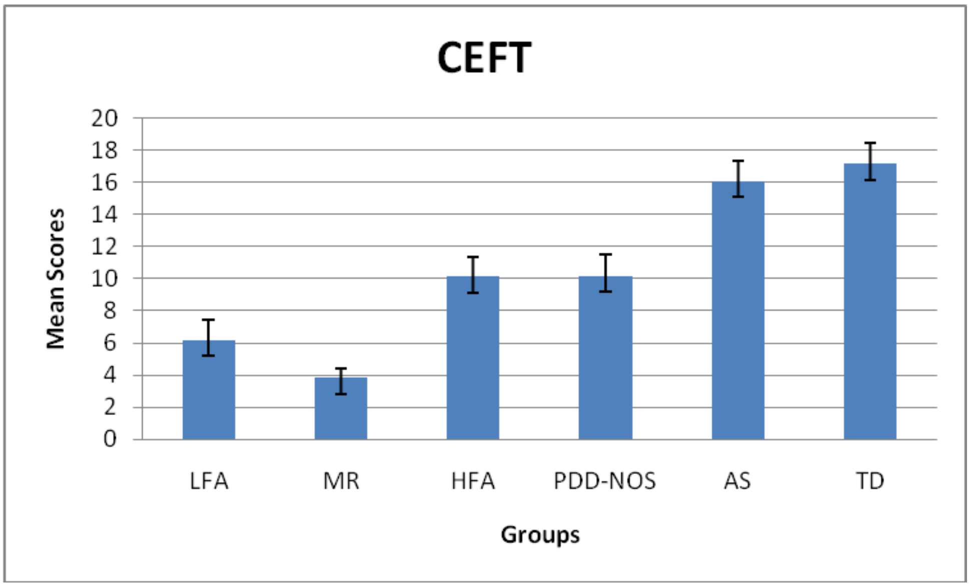


Figure 6. Performance of all groups on the CEFT. The error bars indicate the standard error of means.

With regard to performance on the BD subtest, there was no statistically significant difference between the LFA and MR groups. There was, however, a statistically significant difference in performance between the HFA, AS, PDD-NOS, and TD groups on this task (see Figure 7). The effect size estimate shown in Table 4 indicates that 11% of the variance in BD performance across the latter four groups is explained by group membership. Tukey's HSD post-hoc analysis (see Table 7) showed there was a statistically significant difference in BD performance between the AS and HFA group, with the HFA group performing significantly more poorly than the AS group. There were no other statistically significant group differences in performance on this task.

Table 7

Measures of General Spatial Ability: Post-hoc analysis BD

	Group						
	LFA	MR	AS	PDD-NOS	HFA	TD	
Pairwise Comparison #	(*n* = 15)	(*n* = 16)	(*n* = 23)	(*n* = 17)	(*n* = 23)	(*n* = 23)	*p*
1	31.73 (4.65)	29.63 (3.38)	------	------	------	-----	.158
2	------	------	------	------	43.43 (7.64)	49.39 (11.52)	.201
3	------	------	51.91 (10.73)	------	43.43 (7.64)	------	.030*
4	------	------	------	45.00 (10.41)	43.43 (7.64)	------	.963
5	------	------	51.91 (10.73)	------	------	49.39 (11.52)	.834
6	------	------	51.91 (10.73)	45.00 (10.41)	------	------	.154
7	------	------	------	45.00 (10.41)	------	49.39 (11.52)	.534

Note. Means are presented with standard deviations in parentheses. LFA = low-functioning autism; MR = mentally retarded; HFA = high-functioning autism; AS = Asperger's syndrome; PDD-NOS = pervasive developmental disorder not-otherwise specified; TD = typically developing; BD = Block Design subtest of the WASI.

* $p < .05$.

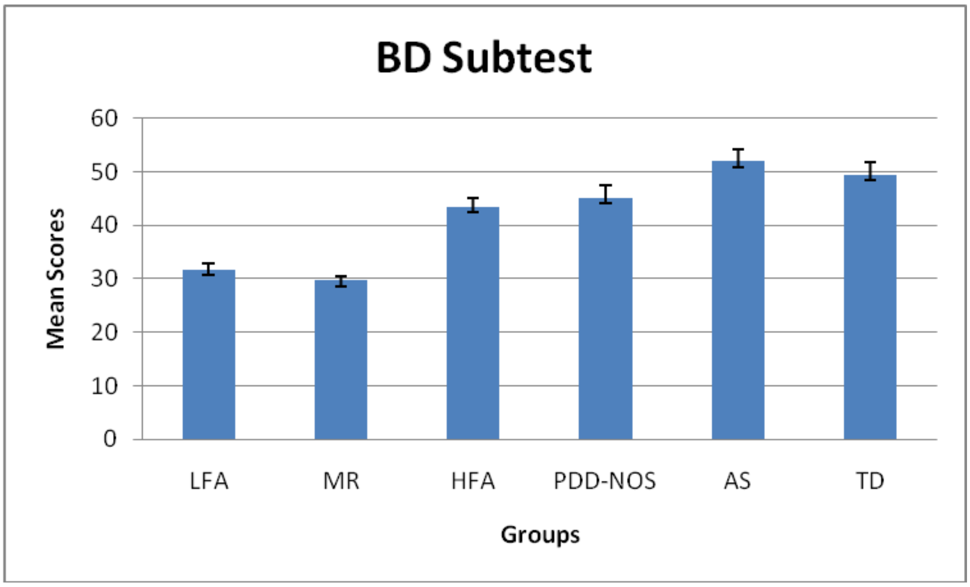


Figure 7. Performance of all groups on the BD subtest of the WASI. The error bars indicate the standard error of means.

The effect of PIQ on general spatial ability. Because, as noted above, there were statistically significant differences between the HFA, AS, PDD-NOS, and TD groups in terms of PIQ, I conducted ANCOVAs on the ROCF, CEFT and BD measures, using PIQ as a covariate.

With regard to the ROCF test, the ANCOVA results, $F(1, 79) = 6.61$, $p = .012$, showed that PIQ was a significant influence on performance. Nonetheless, even after PIQ was controlled for, there was still a statistically significant between-groups difference, $F(3, 79) = 4.08$, $p = .009$, with the HFA and PDD-NOS groups performing significantly more poorly than the TD and AS groups.

With regard to the CEFT, the ANCOVA results, $F(1, 79) = 16.86$, $p < .001$, showed that PIQ was a significant influence on performance. Nonetheless, even after PIQ was controlled for, there was still a statistically significant between-groups difference, $F(3, 79) = 5.75$, $p < .001$, with the HFA and PDD-NOS groups again performing significantly more poorly than the TD and AS groups.

However, with regard to the BD task, no ANCOVA was performed as the BD task is a subtest of the WASI and assess the participant’s performance intelligence. Therefore using PIQ as a covariate when analyzing BD performance would be confounding.

Summary of results: Measures of general spatial ability. Predictions rooted in both the WCC and EPF theories state that ASD individuals should have superior performance to typically developing controls on tasks, such as the ROCF, CEFT, and BD, that require focus on detailed, local-level processing. These predictions were not confirmed by the current data: Overall, the current results suggested that ASD participants performed similarly, and in some cases more poorly, than non-ASD control groups on these measures, irrespective of their intellectual functioning. Hence, the current data do not only stand in contrast to predictions made by the WCC and EPF theories, but they are also not consistent with findings from several previous studies of general spatial ability in ASD (see, e.g., Jarrold, Gilchrist, & Bender, 2005; Jolliffe & Baron-Cohen, 1997; Mottron, Burack, Iarocci, Belleville, & Enns, 2003; Ropar & Mitchell, 2001). The current data are, however, consistent with findings from other more recent studies of general spatial ability in ASD (see, e.g., Daniels, 2009; Edgin & Pennington, 2005).

Measures of Allocentric Spatial Ability

Tables 8 and 9 show the results of two one-way ANOVAs; the first, shown in Table 8, compared the performance of participants in the LFA and MR groups on a measure of allocentric spatial coding ability (the Nine-Box Maze Test), while the second, shown in Table 9, compared the performance of participants in the HFA, AS, PDD-NOS, and TD groups on the same measure.

As Table 8 shows, there was no statistically significant difference between the LFA and MR groups on any of the outcome measures associated with the NBMT. There were, however, statistically significant differences in performance on all three outcome measures between the HFA, AS, PDD-NOS, and TD groups. The effect size estimates shown in Table 9 indicate that, across the latter four groups, 13% of the variance in Object Familiarisation performance, 12% of the variance in FBMT performance, and 19% of variance in NBMT total performance was explained by group membership.

Table 8
NBMT Measure of Allocentric Spatial Ability: ANOVA results LFA and MR groups

Variable	*M* (*SD*)	*df*	*F*	*p*	η^2
Object Familiarisation	6.23 (1.89)	1	0.013	.909	< .001
FBMT	21.90 (3.99)	1	0.001	.968	< .001
NBMT total	38.90 (17.22)	1	0.396	.534	.01

Note. LFA = low-functioning autism (*n* = 15); MR = mentally retarded (*n* = 16); NBMT = Nine-Box Maze Test; FBMT = Five-Box Maze Test. NBMT Total = total score on Nine-Box Maze Test.

Table 9

NBMT Measure of Allocentric Spatial Ability: ANOVA results AS, PDD-NOS, HFA and TD groups

Variable	*M* (*SD*)	*df*	*F*	*p*	η^2
Object Familiarisation	7.24 (1.85)	3	4.091	.009**	.13
FBMT	22.71 (2.89)	3	3.69	.015*	.12
NBMT total	44.40 (16.53)	3	6.23	< .001***	.19

Note. HFA = high-functioning autism (n = 23); AS = aspergers syndrome (n = 23); PDD-NOS = pervasive developmental disorder not-otherwise specified (n = 17); TD = typically developing (n = 23); NBMT = Nine-Box Maze Test; FBMT = Five-Box Maze Test. NBMT Total = total score on Nine-Box Maze Test.

* $p < .05$. **$p < .01$. *** $p < .001$

Tukey's HSD post-hoc analysis (see Table 10) showed that there was a statistically significant difference in Object Familiarisation performance between the HFA and TD groups, with the HFA group performing significantly more poorly than the TD group. On the FBMT, Tukey's HSD post-hoc analysis (see Table 11) showed that there was a statistically significant difference in performance between the PDD-NOS and TD groups, with the PDD-NOS group performing significantly more poorly than the TD group. On the NBMT total measure, Tukey's HSD post-hoc analysis (see Table 12) showed that there was a statistically significant difference in performance between the HFA and TD groups and between the PDD-NOS and TD groups, with the HFA and PDD-NOS groups performing significantly more poorly than the TD group. There were no statistically significant differences on all these measures between participants in AS and TD groups, or between the ASD groups (see Figure 8).

Table 10

Measures of Allocentric Spatial Ability Post-Hoc analysis: Object Familiarisation

	Group						
	LFA	MR	AS	PDD-NOS	HFA	TD	
Pairwise Comparison #	(*n* = 15)	(*n* = 16)	(*n* = 23)	(*n* = 17)	(*n* = 23)	(*n* = 15)	*p*
1	6.27 (2.28)	6.19 (1.52)	------	------	------	------	.909
2	------	------	------	------	6.39 (2.06)	8.13 (1.25)	.006**
3	------	------	7.43 (1.56)	------	6.39 (2.06)	------	.191
4	------	------	------	6.88 (2.13)	6.39 (2.06)	------	.832
5	------	------	7.43 (1.56)	------	------	8.13 (1.25)	.538
6	------	------	7.43 (1.56)	6.88 (2.13)	------	------	.761
7	------	------	------	6.88 (2.13)	------	8.13 (1.25)	.133

Note. Means are presented with standard deviations in parentheses. LFA = low-functioning autism; MR = mentally retarded; HFA = high-functioning autism; AS = Asperger's syndrome; PDD-NOS = pervasive developmental disorder not-otherwise specified; TD = typically developing.

**p < .01.

Table 11

Measures of Allocentric Spatial Ability Post-Hoc analysis: FBMT

	Group						
	LFA	MR	AS	PDD-NOS	HFA	TD	
Pairwise Comparison #	(*n* = 15)	(*n* = 16)	(*n* = 23)	(*n* = 17)	(*n* = 23)	(*n* = 15)	*p*
1	21.93 (4.79)	21.88 (3.22)	------	------	------	------	.968
2	------	------	------	------	22.09 (4.07)	23.91 (0.42)	.121
3	------	------	23.17 (2.06)	------	22.09 (4.07)	------	.544
4	------	------	------	21.19 (3.23)	22.09 (4.07)	------	.749
5	------	------	23.17 (2.06)	------	------	23.91 (0.42)	.801
6	------	------	23.17 (2.06)	21.19 (3.23)	------	------	.129
7	------	------	------	21.19 (3.23)	------	23.91 (0.42)	.017*

Note. Means are presented with standard deviations in parentheses. LFA = low-functioning autism; MR = mentally retarded; HFA = high-functioning autism; AS = Asperger's syndrome; PDD-NOS = pervasive developmental disorder not-otherwise specified; TD = typically developing; FBMT = Five-Box Maze Test.

*$p < .05$.

Table 12

Measures of Allocentric Spatial Ability Post-Hoc analysis: NBMT total

	Group						
	LFA	MR	AS	PDD-NOS	HFA	TD	
Pairwise Comparison #	(*n* = 15)	(*n* = 16)	(*n* = 23)	(*n* = 17)	(*n* = 23)	(*n* = 23)	*p*
1	40.93 (14.79)	37.00 (19.52)	------	------	------	------	.534
2	------	------	------	------	39.09 (17.64)	53.87 (4.93)	.008**
3	------	------	46.87 (14.02)	------	39.09 (17.64)	------	.310
4	------	------	------	34.88 (21.50)	39.09 (17.64)	------	.829
5	------	------	46.87 (14.02)	------	------	53.87 (4.93)	.405
6	------	------	46.87 (14.02)	34.88 (21.50)	------	------	.080
7	------	------	------	34.88 (21.50)	------	53.87 (4.93)	< .001***

Note. Means are presented with standard deviations in parentheses. LFA = low-functioning autism; MR = mentally retarded; HFA = high-functioning autism; AS = Asperger's syndrome; PDD-NOS = pervasive developmental disorder not-otherwise specified; TD = typically developing; NBMT = Nine-Box Maze Test.

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

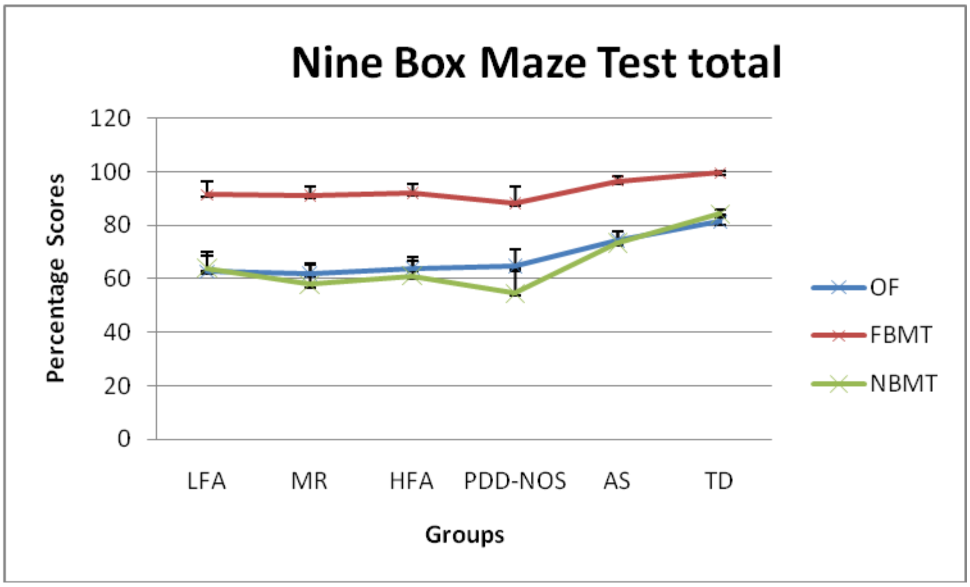


Figure 8. Performance by all groups on the three outcome measures associated with Nine Box Maze Test total. The error bars indicate the standard error of percentage scores.

The second measure of allocentric spatial ability used in the study was the Spatial Place Coding task. The outcome measure associated with this task was the participants' mean error scores. (This score was calculated by subtracting the participant's response locations (in mm) from the true object location.) Again, and for the same reasons as explained earlier, one set of analyses compared the LFA and MR groups to one another, while a separate set of analyses compared the HFA, PDD-NOS, AS, and TD groups to one another.

With regard to SPC mean error scores across the 24 trials by the LFA and MR participants (data shown in Table 13), a repeated-measures ANOVA showed there was a statistically significant main effect of group, $F(1, 29) = 5.60$, $p = .025$, $\eta^2 = .16$, but no statistically significant main effect of trials, $F(7, 203) = .379$, $p = .914$, $\eta^2 = .012$, and no significant group x trials interaction, $F(7, 203) = 0.732$, $p = .645$, $\eta^2 = .025$. The LFA group performed significantly more poorly than the MR group. This piece of data suggests that LFA participants have impaired allocentric spatial coding compared to MR participants.

Table 13
SPC Mean Error Scores: LFA and MR groups

Object Position	True Object Location	Groups LFA (*n* = 15)	MR (*n* = 16)
1	89mm	113.67 (133.05)	52.71 (35.36)
2	178mm	90.93 (77.12)	61.81 (32.57)
3	267mm	96.56 (63.78)	66.94 (31.59)
4	356mm	104.20 (45.29)	81.33 (38.96)
5	445mm	115.20 (75.12)	62.53 (33.07)
6	534mm	119.22 (88.77)	80.19 (38.75)
7	623mm	101.04 (108.67)	71.88 (28.26)
8	712mm	128.64 (192.90)	48.88 (34.75)

Note. Means are presented with standard deviations in parentheses. LFA = low-functioning autism; MR = mentally retarded; SPC = Spatial Place Coding task.

With regard to SPC mean error scores across the 24 trials by the HFA, PDD-NOS, AS, and TD participants (data shown in Table 14), a repeated-measures ANOVA showed there was a statistically significant main effect of group, $F(3, 82) = 7.789$, $p = .004$, $\eta^2 = .15$, but no statistically significant main effect of trials, $F\ (7, 574) = 1.991$, $p = .054$, $\eta^2 = .02$, and no significant group x trials interaction, $F(21, 574) = 1.020$, $p = .436$, $\eta^2 = .04$. Tukey's HSD post-hoc analysis showed statistically significant differences between the HFA and TD groups and between the PDD-NOS and TD groups, with the HFA and PDD-NOS groups performing significantly more poorly than the TD group. This piece of data suggests that HFA and PDD-NOS participants have impaired allocentric spatial coding compared to TD participants.

Table 14
SPC Mean Error: AS, PDD-NOS, HFA and TD groups

Object Position	True Object Location	Groups AS (*n* = 23)	PDD-NOS (*n* = 17)	HFA (*n* = 23)	TD (*n* = 23)
1	89mm	27.81 (31.77)	84.82 (144.33)	64.55 (72.59)	21.48 (24.67)
2	178mm	29.42 (30.71)	78.76 (79.24)	81.83 (70.31)	35.28 (26.57)
3	267mm	59.00 (48.71)	81.78 (56.66)	83.36 (90.83)	38.62 (26.66)
4	356mm	53.70 (52.55)	77.61 (60.45)	91.10 (86.05)	33.58 (21.38)
5	445mm	44.51 (34.90)	51.03 (31.49)	79.41 (78.89)	44.85 (44.72)
6	534mm	57.06 (55.65)	76.47 (43.74)	76.13 (86.08)	43.46 (33.84)
7	623mm	38.32 (22.87)	87.37 (91.87)	71.01 (58.78)	38.62 (40.31)
8	712mm	30.23 (43.40)	62.57 (64.60)	69.13 (82.32)	31.64 (43.61)

Note. Means are presented with standard deviations in parentheses. AS = Asperger's syndrome; PDD-NOS = pervasive developmental disorder not-otherwise specified; HFA = high-functioning autism; TD = typically developing; SPC = Spatial Place Coding task.

The effect of PIQ on allocentric spatial ability. Because, as noted above, there were statistically significant differences between the HFA, AS, PDD-NOS, and TD groups in terms of PIQ, I conducted ANCOVAs on the data derived from the NBMT and SPC tasks, using PIQ as a covariate.

With regard to the NBMT Object Familiarisation data, the ANCOVA results, $F(1, 78) = 0.37$, $p = .543$, showed that PIQ did not have a significant influence on performance. The same was true with regard to the FBMT and NBMT total data: in both cases, the ANCOVA results were not statistically significant, $F(1, 80) = 1.87$, $p = .176$, and $F(1, 80) = 3.06$, $p = .084$, respectively.

With regard to the SPC mean error data, the ANCOVA results, $F(1, 28)= 0.48$, $p = .491$ showed that PIQ did not have a significant effect on the group's performance.

Taken together, these results lead to the conclusion that any observed between-group differences on the NBMT and on the SPC were due to unique variation in allocentric spatial coding ability across the groups (i.e., that such between-group differences in allocentric ability cannot be entirely accounted for by between-group variance in intellectual functioning).

Summary of results: Measures of allocentric spatial coding. Predictions derived from WCC theory state that ASD individuals should show *impaired* performance on allocentric spatial coding tasks, such as the NBMT and SPC, relative to typically developing controls; in contrast, predictions derived from EPF theory state that ASD individuals should show *intact* performance on such tasks relative to typically developing controls.

These predictions were partially confirmed by the current data. Specifically, as predicted by the WCC theory, LFA, HFA, and PDD-NOS participants performed poorly, relative to their matched healthy controls, on the allocentric spatial coding tasks. The HFA and PDD-NOS individuals performed relatively poorly on both the NBMT and the SPC, whereas the LFA individuals performed similarly to the MR group on the NBMT and more poorly on the SPC. As predicted by the EPF theory, however, the AS group performed similarly to the TD group on both tasks, suggesting intact allocentric spatial coding in those individuals.

Hence, the current data is partially consistent with findings from previous studies of allocentric spatial coding ability in ASD (see, e.g., Daniels, 2009; Pertini, 2004). The data from the AS group, and the LFA group on the NBMT, confirm the prediction of the EPF theory. On the other hand, the data from the HFA and PDD-NOS groups on, both tasks, confirm the prediction made by the WCC and are consistent with the findings by Daniels (2009) and Pertini (2004).

Measures of Egocentric Spatial Ability

The first egocentric spatial coding task used in this study was the Spatial Response Learning task. The outcome measure associated with this task was the participants' mean error scores. (This score was calculated by subtracting the participant's response locations (in mm) from the true object location.) Again, and for the same reasons as explained earlier, one set of analyses compared the LFA and MR groups to one another, while a separate set of analyses compared the HFA, PDD-NOS, AS, and TD groups to one another.

With regard to SRL mean error scores across the 8 trials by the LFA and MR participants (data shown in Table 15), a repeated-measures ANOVA showed there was a statistically significant main effect of group, $F(1, 29)= 5.844$, $p = .022$, $\eta^2 = .17$, but no statistically significant main effect of trials, $F(7, 203)= 1.952$, $p = .063$, $\eta^2 = .06$, and no significant group x trials interaction, $F(7, 203)= 1.265$, $p = .269$, $\eta^2 = .04$. The LFA group performed significantly more poorly than the MR group. This piece of data suggests that LFA participants have impaired egocentric spatial coding compared to MR participants.

Table 15
SRL Mean Error Score: LFA and MR groups

		Groups	
Object Position	True Object Location	LFA (n = 15)	MR (n = 16)
1	89mm	69.33 (93.26)	62.06 (42.28)
2	178mm	96.60 (75.75)	40.25 (48.97)
3	267mm	58.53 (89.78)	51.31 (31.10)
4	356mm	85.20 (81.53)	36.81 (22.72)
5	445mm	151.87 (188.64)	69.88 (63.09)
6	534mm	115.60 (126.38)	40.19 (30.48)
7	623mm	98.53 (118.95)	44.75 (46.68)
8	712mm	108.73 (92.34)	54.56 (40.51)

Note. LFA = low-functioning autism; MR = mentally retarded; SRL = Spatial Response Learning task.

With regard to the SRL mean error scores across the 8 trials by the HFA, PDD-NOS, AS, and TD participants (data shown in Table 16), a repeated-measures ANOVA showed there was a statistically significant main effect of group, $F(3, 81)= 4.757$, $p = .004$, $\eta^2 = .15$, and trials, $F(7, 567)= 2.400$, $p = .020$, $\eta^2 = .03$, but no significant group x trials interaction, *F*(21, 567)= 1.446, p = .436, η^2 = .05. At several object locations, particularly numbers 4 and 5, the mean error scores for HFA participants were much greater than those for AS, PDD-NOS, and TD participants. These locations are roughly in the middle of the cardboard before it is moved either to the left or the right. Poor performance by the HFA participants suggests that these individuals were possibly still placing the object in the centre of the cardboard once the cardboard has been moved. This suggests impaired allocentric spatial coding as the individuals are placing the object back onto the cardboard in relation to themselves rather than paying attention to external cues.

Tukey’s HSD post-hoc analysis showed statistically significant differences between the HFA and TD groups and between the HFA and AS groups. The HFA group performed significantly more poorly than the TD and AS groups. This piece of data suggests that HFA and PDD-NOS participants have impaired egocentric spatial coding compared to TD and AS participants.

Table 16

SRL Mean Error Score: AS, PDD-NOS, HFA and TD groups

		Groups			
Object Position	True Object Location	AS (*n* = 23)	PDD-NOS (*n* = 23)	HFA (*n* = 23)	TD (*n* = 23)
1	P1 (89mm)	48.43 (37.12)	50.65 (47.08)	70.55 (84.41)	44.74 (44.05)
2	P2 (178mm)	44.17 (35.72)	79.06 (85.92)	96.45 (110.26)	40.91 (39.45)
3	P3 (267mm)	31.13 (30.89)	36.18 (31.93)	50.86 (81.18)	22.96 (18.24)
4	P4 (356mm)	51.26 (78.67)	44.76 (30.79)	120.77 (168.52)	39.61 (25.60)
5	P5 (445mm)	44.43 (29.87)	35.18 (33.55)	123.82 (185.22)	31.91 (25.72)
6	P6 (534mm)	39.52 (60.13)	40.47 (27.44)	69.55 (76.00)	30.22 (23.39)
7	P7 (623mm)	58.09 (98.94)	33.59 (26.27)	69.55 (78.52)	25.91 (19.76)
8	P8 (712mm)	41.17 (42.35)	73.82 (104.36)	55.09 (74.92)	38.43 (60.54)

Note. Means are presented with standard deviations in parentheses. AS = Asperger's syndrome; PDD-NOS = pervasive developmental disorder not - otherwise specified; HFA = high-functioning autism; TD = typically developing; SRL = Spatial Response Learning task.

Another task that examined egocentric spatial ability in the current sample was the visible-target CG Arena trials. This task required egocentric spatial coding as the participants were required to locate a visible blue target within the room, and could do so with reference to their own position in the room and without having to make use of landmarks or the relations among landmarks. Again, and for the same reasons as explained earlier, one set of analyses compared the LFA and MR groups to one another, while a separate set of analyses compared the HFA, PDD-NOS, AS, and TD groups to one another.

With regard to the average path length on the four visible trials by the LFA and MR participants, a one-way ANOVA showed there were no statistically significant between-group differences, $F(1, 28) = 0.624$, $p = .436$, $\eta^2 = .02$. With regard to the average path length on the four visible trials by the HFA, AS, PDD-NOS and TD participants, a one-way ANOVA also showed there were no statistically significant between-group differences, $F(3, 82) = 1.349$, $p = .264$, $\eta^2 = .05$. These results indicate that participants in all groups have intact motor and visuoperceptual ability and that the ASD groups have intact (but not superior) egocentric spatial ability compared to the non-ASD control groups on this task.

The effect of PIQ on egocentric spatial ability. Because, as noted above, there were statistically significant differences between the HFA, AS, PDD-NOS, and TD groups in terms of PIQ, I conducted ANCOVAs on the data derived from the SRL task, using PIQ as a covariate.

With regard to the SRL mean error data, the ANCOVA results $F(1, 80) = 1.42$, $p = .236$ showed that PIQ did not have a significant effect on the trials or group performance.

These results lead to the conclusion that any observed between-group differences on SRL task were due to unique variation in egocentric spatial coding ability across the groups (i.e., that such between-group differences in egocentric ability cannot be entirely accounted for by between-group variance in intellectual functioning).

Summary of results: Measures of egocentric spatial coding. Predictions derived from both the WCC and EPF theories state that ASD individuals should show *intact* performance on egocentric spatial coding tasks, such as the SRL and CG Arena visible-target trials, relative to typically developing controls.

These predictions were partially confirmed by the current data. As predicted by both theories, the AS and PDD-NOS groups performed similarly, relative to their matched healthy controls, on both egocentric spatial coding tasks. The HFA and LFA individuals performed poorly on the SRL task, whereas both groups performed similarly to the their IQ-matched control groups on the visible trials of the CG Arena. This task, however, was not sensitive to the possible sensory difficulties that were experienced by the ASD individuals which may have possibly affected the performance by these individuals. This problem will be discussed further in the discussion.

Hence, the current data from the HFA and LFA groups on the SRL task does not only stand in contrast to predictions made by the WCC and EPF theories, but they are also not consistent with findings from previous studies of egocentric spatial coding in ASD (see, e.g., Daniels, 2009; Pertini, 2004). The performance by the AS and PDD-NOS groups on the SRL task, and by all the groups on the visible trials of the CG Arena, confirm the predictions made by both the WCC and EPF theories. These data are also consistent with findings presented by Daniels (2009) and Pertini (2004).

Measures of Spatial Navigation

Egocentric spatial navigation ability. As discussed in the previous section and as shown in Figure 9, the ASD groups all performed similarly to their IQ-matched control groups. Hence, the current data suggest that the ASD individuals have intact egocentric spatial navigational ability.

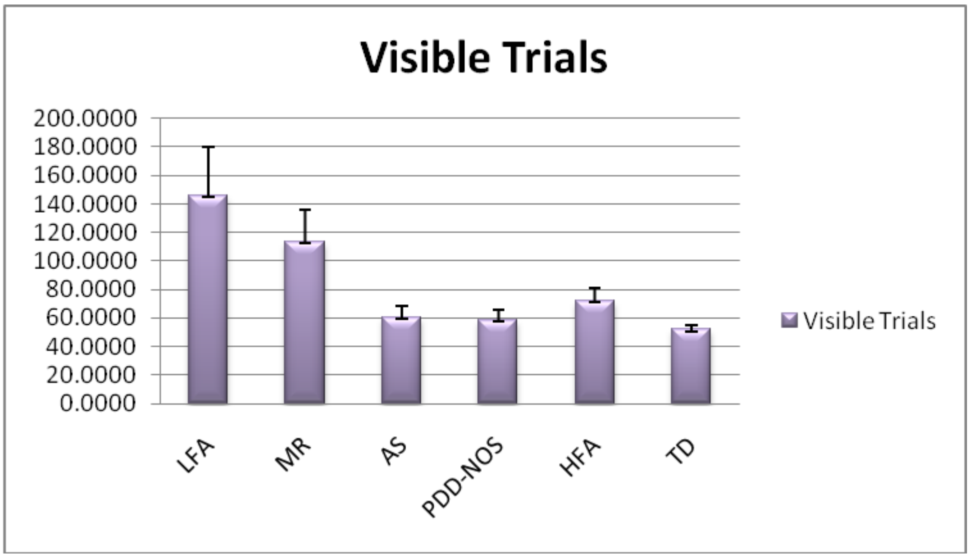


Figure 9. Mean path length on the CG Arena visible target trials. The error bars indicate the standard error of means.

Allocentric spatial navigation ability. Data from the CG Arena invisible target and probe trials delivered several different dependent variables, each of which is discussed in turn below.

With regard to the number of times the participants successfully located the target across the 16 invisible trials, results from two separate one-way ANOVAs (see Tables 17 and 18) indicated that there were no statistically significant between-group differences. In other words, all participants, regardless of group assignment, located and re-located the invisible target equally successfully.

Table 17
CG Arena: ANOVA results LFA and MR groups

Variable	*M* (*SD*)	*F*	*p*	η^2
Visible trials: path length	129.32 (111.56)	0.62	.436	.02
Invisible trials: Times target found	11.29 (2.07)	1.35	.255	.04
Probe trial dwell time	37.96 (22.56)	1.21	.280	.04
ORT score	2.58 (2.21)	2.18	.151	.07
ART score	7.17 (2.99)	0.26	.604	.01

Note. LFA = low-functioning autism (*n* = 15); MR = mentally retarded (*n* = 16); ORT = Object Recognition Task; ART = Arena Reconstitution Task. Degrees of freedom for each comparison = 1.

Table 18
CG Arena: ANOVA results AS, PDD-NOS, HFA and TD groups

Variable	*M* (*SD*)	*F*	*p*	η^2
Visible trials: path length	60.84 (34.28)	1.35	.264	.05
Invisible trials: Times target found	12.40 (1.57)	0.38	.768	.01
Probe trial: dwell time	53.24 (26.17)	3.16	.029*	.10
ORT score	3.87 (2.59)	5.02	.003**	.16
ART score	9.34 (6.25)	3.61	.017*	.12

Note. HFA = high-functioning autism (*n* = 23); AS = Asperger's syndrome (*n* = 23); PDD-NOS = pervasive developmental disorder not-otherwise specified (*n* = 17); TD = typically developing (*n* = 23); ORT = Object Recognition Task; ART = Arena Reconstitution Task. Degrees of freedom for each comparison = 3.
$^*p < .05$. $^{**}p < .01$.

Figures 10 and 11 present data regarding the path length participants took to go from their starting position to the target on each of the 16 invisible trials. A repeated-measures ANOVA comparing path lengths of the LFA and MR groups revealed no statistically significant main effect of trials, $F(12, 348)= 0.513$, $p = .906$, $\eta^2 = .02$, or of group, $F(1, 29)= 1.254$, $p = .272$, $\eta^2 = .04$, and no significant group x trials interaction, $F(12, 348) = 0.499$, $p = .914$, $\eta^2 = .02$.

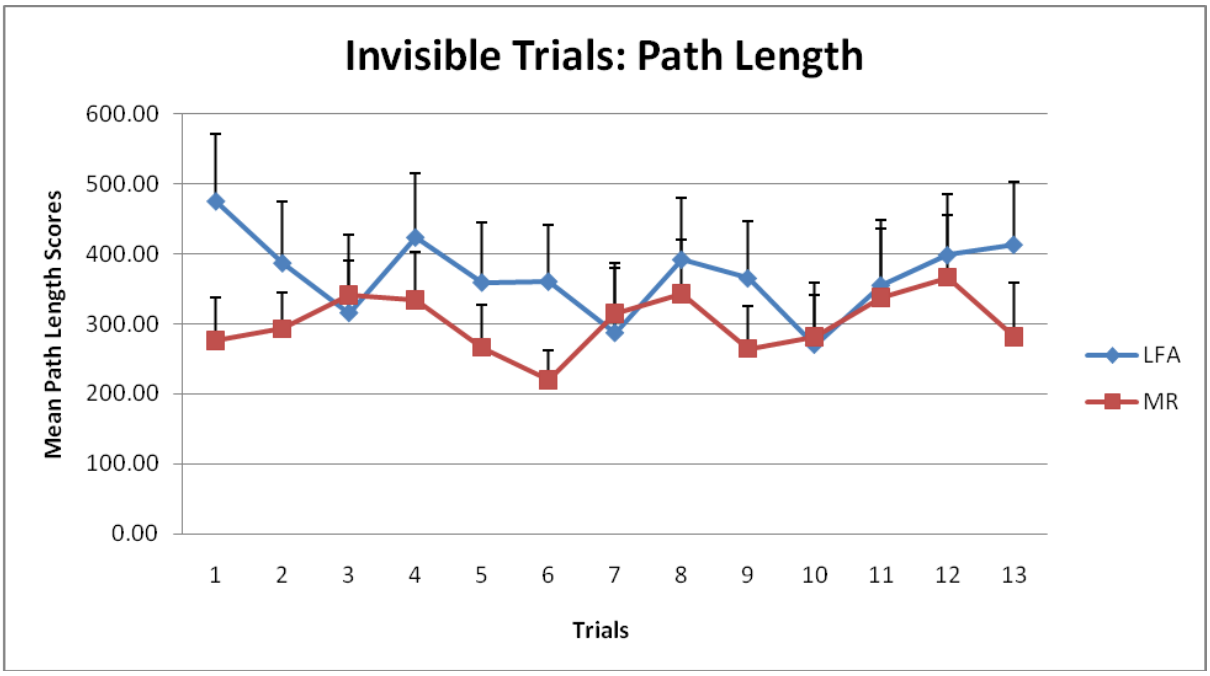


Figure 10. Mean path length of participants in the LFA and MR groups on the CG Arena invisible target trials. The error bars indicate the standard error of means.

A similar repeated-measures ANOVA comparing path lengths of the HFA, AS, PDD-NOS, and TD groups revealed no statistically significant main effect of trials, $F(12, 984)= 1.343$, $p = .188$, $\eta^2 = .02$, and no significant group x trials interaction, $F(36, 984)= 1.173$, $p = .226$, $\eta^2 = .04$. There was, however, a statistically significant main effect of group, $F(3, 82) = 3.667$, $p = .016$, $\eta^2 = .12$, with participants in the HFA group (252.8) taking a significantly longer mean path length to the target than those in the AS group (124.39).

Taken together, these path length data suggest that (1) LFA participants perform as well as MR participants on a task assessing allocentric spatial navigation; (2) HFA participants perform significantly more poorly than AS participants on the same navigation task; and (3) AS, PDD-NOS, and HFA participants perform as well as TD participants on the same task. Therefore, the ASD groups perform similarly to their IQ-matched controls on this task.

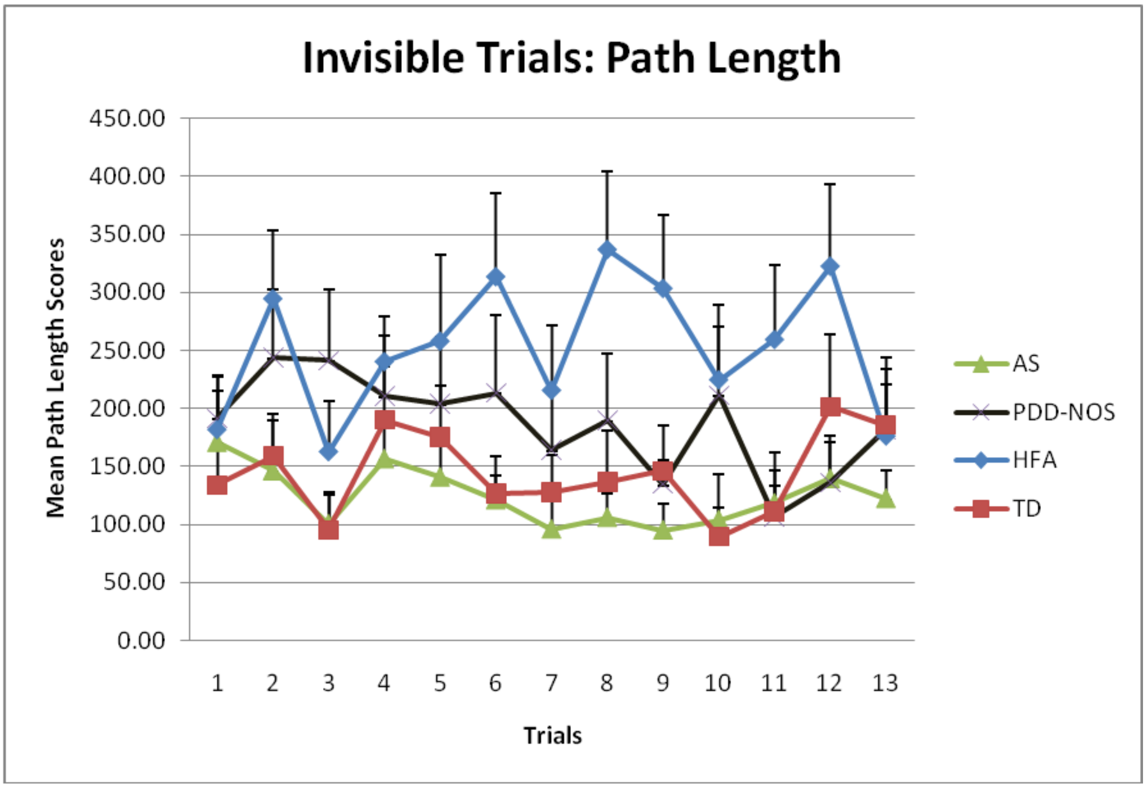


Figure 11. Mean path length of participants in the HFA, AS, PDD-NOS, and TD groups on the CG Arena invisible target trials. The error bars indicate the standard error of means.

With regard to analysis of data from the probe trial, as Table 17 shows there were no statistically significant differences between the LFA and MR groups in terms of mean dwell (i.e., the time spent searching the quadrant in which the target had been located during the invisible target trials; this was the NW quadrant). However, as Table 18 shows, there was a statistically significant difference between the HFA, AS, PDD-NOS, and TD groups in terms of dwell time. The effect size estimate shown in Table 18 indicates that 10% of the variance in dwell time across the latter four groups is explained by group membership. Post-hoc analysis using the least-significant difference (LSD) procedure showed that participants in the AS and TD groups spent significantly more time in the NW quadrant (AS, M = 62.22, SD = 21.55; TD, M = 59.64, SD = 25.44) during the probe trial than did participants in the HFA group (M = 43.03, SD = 26.17). There was no statistically significant difference between the mean dwell time of the PDD-NOS group and those of the TD, AS or HFA groups, although participants in the PDD-NOS group (M = 46.26, SD = 28.10) did spend less time in the NW quadrant during the probe trials than did participants in the TD and AS groups.

Interim summary: Spatial navigation data. Analyses of CG Arena data thus far suggest that participants in the LFA, HFA, PDD-NOS, and AS groups successfully found the invisible target as many times as did participants in their IQ-matched control groups..

Additionally, the ASD participants found the target just as efficiently (i.e., using similar path lengths) as their IQ-matched controls. Probe trial data suggested, however, that HFA and PDD-NOS participants may have developed less robust cognitive maps than other participants: On that trial, they spent less time exploring the NW quadrant, where the target had previously been located, than did the AS and TD participants. This latter piece of data suggests that investigation of the types of search strategies used by the HFA and PDD-NOS participants is warranted, so as to better understand how these individuals are successfully negotiating the environment in order to find the target.

Also when compared with the other groups, the LFA and MR groups spent less time in the NW quadrant searching for the target on the probe trial and had a longer mean path length in comparison to the TD and AS groups. Even though no direct comparisons have been done between the LFA and MR groups with the other groups, the results from these groups, specifically regarding target crossing, path length and dwell time, showed a need to better understand how these individuals are locating their targets within the Arena. The data showed a need to establish whether the LFA and MR groups are possibly using alternative types of strategies during navigation.

Spatial search strategies. I examined and analysed the types of search strategies that the participants used while navigating the CG Arena during the invisible target trials. The strategies were classified using a taxonomy described by Kallai, Makany, Karadi, and Jacobs (2005). More specifically, I attempted to classify the participants' search paths across all 13 invisible target trials as being predominantly one of these strategies: Thigmotaxis, Circle, Visual Scan, and Enfilading. Search paths that were not clearly distinguishable as one of those four (i.e., that did not meet any of the criteria explained below) were described as an Other/None strategy. Only 13 invisible trials were examined as the first 3 trials were excluded as the participants were still becoming acquainted with the room on these trials.

The *Thigmotaxis* strategy is being used when the participant follows a circular path along and close to the wall of the arena. The *Circle* strategy is being used when the participant follows an arch-shaped path inside the arena, but does not use the wall as a guide. The *Visual Scan* strategy is being used when an individual stands in a fixed position and turns around to examine the distal cues before heading in a particular direction. The *Enfilading* strategy involves small position corrections and non-strategic motions. Examples of each of these strategies, taken from participants in the current study, are shown in Figure 12.

Chi-squared tests were used to examine whether there were any associations between group membership and type of strategy used. Analysis of search strategies used by the LFA and MR participants showed that there was no statistically significant between-group difference, $\chi^2(4, N = 31) = 0.90$, $p = .925$. The LFA participants used the Thigmotaxis strategy most frequently, followed by the Visual Scan strategy. The MR participants used both the Thigmotaxis and Visual Scan strategy most frequently, followed by the Other/None strategy.

Analysis of search strategies used by the HFA, AS, PDD-NOS, and TD participants showed a statistically significant association between type of search strategy and group membership, $\chi^2(12, N = 86)= 21.60$, $p = .042$. The TD and AS participants used the Visual Scan strategy most frequently in comparison to the HFA and PDD-NOS groups. Even though the HFA and PDD-NOS participants made use of the Visual Scan strategy less frequently than the AS and TD participants, it was still the most frequently used strategy by both groups. Otherwise stated, most of the HFA, PDD-NOS, AS, and TD participants used the Visual Scan strategy, with only a small percentage of the HFA and PDD-NOS participants tending to use other, less efficient, strategies (see Figure 13).

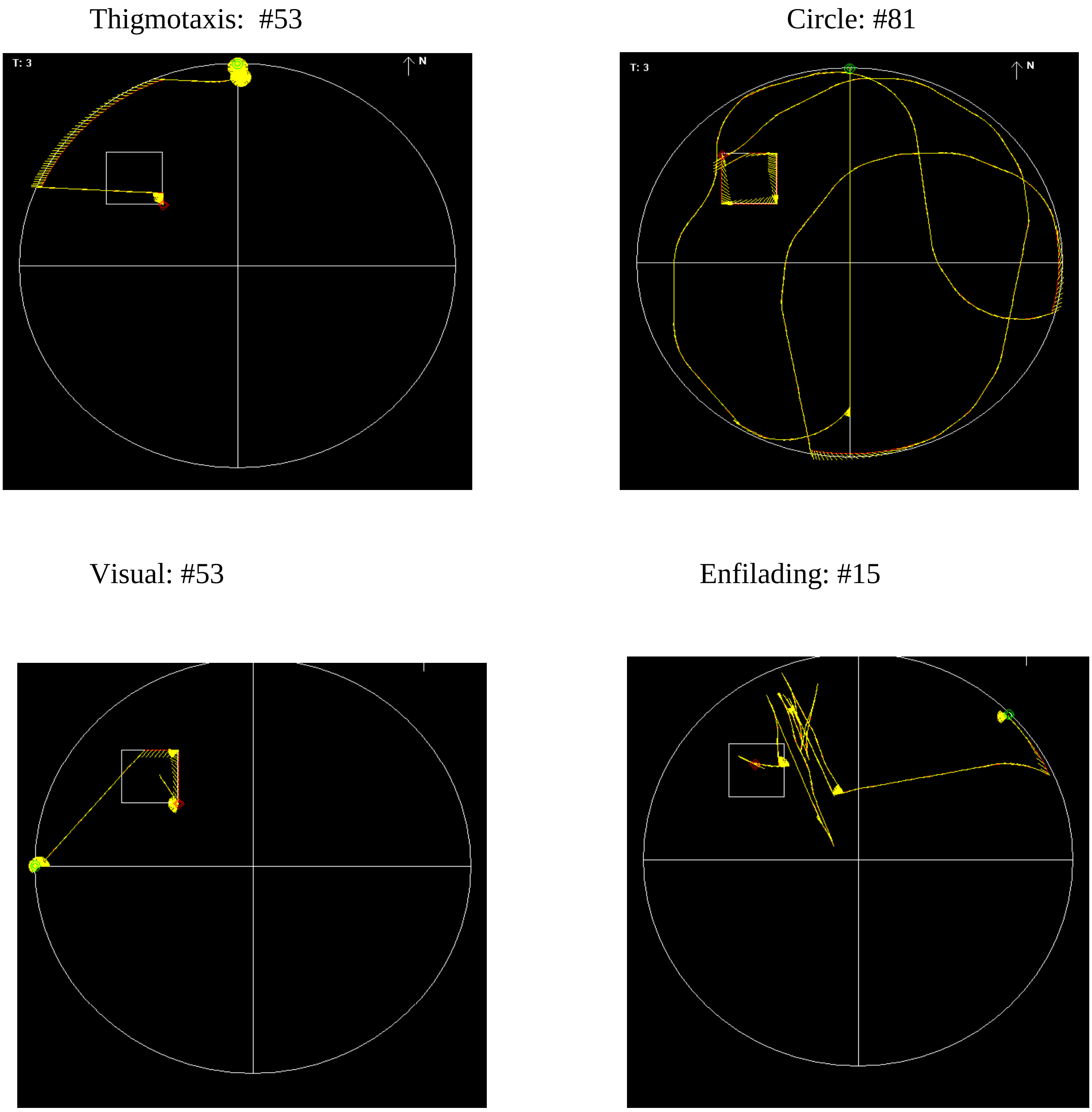


Figure 12. Search strategies used by participants in the current study. The top panel shows the Thigmotaxis strategy, as employed by participant number 53 (LFA), and the Circle strategy, as employed by participant number 81 (HFA). The next panel down shows the Visual strategy, as employed by participant number 53 (LFA), and the Enfilading strategy, as employed by participant number 15 (HFA).

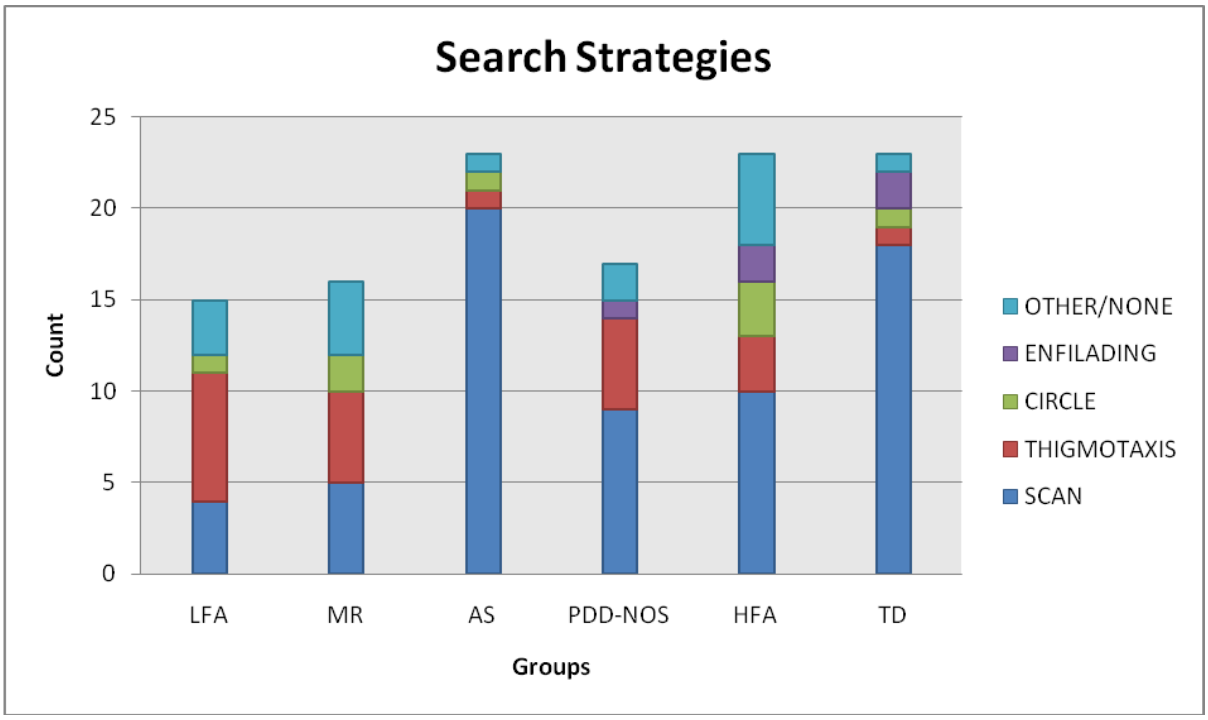


Figure 13. CG Arena invisible target trial search strategies.

ORT data. Analysis of data from the Object Recognition Test focused on *d'* (d prime) scores (see the Statistical Analysis subsection for more details on how these scores were derived). Results from a one-way ANOVA (see Table 17) comparing data from the LFA and MR groups showed there were no statistically significant between-group differences. Results from a similar one-way ANOVA (see Table 18) comparing data from the HFA, AS, PDD-NOS, and TD groups showed, in contrast, that there were statistically significant between-group differences. The effect size estimate shown in Table 18 indicates that 16% of the variance in ORT performance across the latter four groups is explained by group membership. Tukey's HSD post-hoc analysis (see Table 19) showed that participants in the HFA group performed statistically significantly more poorly than did participants in TD and AS groups. This pattern of data implies that TD and AS individuals showed better non-spatial recognition memory performance than the HFA participants. It might also suggest that the TD and AS participants paid more attention to the visual cues present on the walls than did the HFA participants.

ART data. Analysis of data from the Arena Reconstitution Task focused on the ART Total score (see the Statistical Analysis subsection for more details of how these scores were derived). Results from a one-way ANOVA (see Table 17) comparing data from the LFA and MR groups showed there were no statistically significant between-group differences. Results from a similar one-way ANOVA comparing data from the HFA, AS, PDD-NOS, and TD groups (see Table 18) showed, in contrast, that there were statistically significant between-group differences. The effect size estimate shown in Table 18 indicates that 12% of the variance in ART performance across the latter four groups is explained by group membership. Tukey's HSD post-hoc analysis (see Table 20) showed that participants in the HFA group performed statistically significantly more poorly than did participants in the AS group. There were no significant differences between the ART scores of the AS, PDD-NOS, and TD groups. This pattern of data suggests that, although AS participants tended to show stronger cognitive mapping ability than HFA participants, both HFA and AS participants showed intact cognitive mapping ability relative to the TD participants.

Table 19

Pairwise Post-hoc Comparisons: ORT data

	Group						
Pairwise Comparison #	LFA (*n* = 15)	MR (*n* = 16)	AS (*n* = 23)	PDD-NOS (*n* = 17)	HFA (*n* = 23)	TD (*n* = 23)	*p*
1	1.98 (2.25)	3.13 (2.09)	------	------	------	------	.151
2	------	------	------	------	2.30 (2.57)	4.51 (2.06)	.016*
3	------	------	4.89 (1.89)	------	2.30 (2.57)	------	.003**
4	------	------	------	3.64 (3.21)	2.30 (2.57)	------	.326
5	------	------	4.89 (1.89)	------	------	4.51 (2.06)	.948
6	------	------	4.89 (1.89)	3.64 (3.21)	------	------	.374
7	------	------	------	3.64 (3.21)	------	4.51 (2.06)	.679

Note. Means are presented with standard deviations in parentheses. LFA = low-functioning autism; MR = mentally retarded; AS = Asperger's syndrome; PDD-NOS = pervasive developmental disorder not-otherwise specified; HFA = high-functioning autism; TD = typically developing; ORT = Object Recognition Task.

*$p < .05$. **$p < .01$.

Table 20

Pairwise Post-hoc Comparisons: ART data

	Group						
Pairwise Comparison #	LFA (n = 15)	MR (n = 16)	AS (n = 23)	PDD-NOS (n = 17)	HFA (n = 23)	TD (n = 23)	p
1	6.86 (2.48)	7.42 (3.42)	------	------	------	------	.604
2	------	------	------	------	7.48 (4.99)	8.91 (3.62)	.848
3	------	------	12.70 (9.02)	------	7.48 (4.99)	------	.021*
4	------	------	------	7.58 (3.86)	7.48 (4.99)	------	.999
5	------	------	12.70 (9.02)	------	------	8.91 (3.62)	.148
6	------	------	12.70 (9.02)	7.58 (3.86)	------	------	.063
7	------	------	------	7.58 (3.86)	------	8.91 (3.62)	.911

Note. Means are presented with standard deviations in parentheses. LFA = low-functioning autism; MR = mentally retarded; AS = Asperger's syndrome; PDD-NOS = pervasive developmental disorder not-otherwise specified; HFA = high-functioning autism; TD = typically developing; ART = Arena Reconstitution Task.

*$p < .05$.

The effect of PIQ on spatial navigational ability. Because, as noted above, there were statistically significant differences between the HFA, AS, PDD-NOS, and TD groups in terms of PIQ, I conducted ANCOVAs on the data derived from the CG Arena, ORT, and ART, using PIQ as a covariate.

With regard to CG Arena invisible target trial path length data, the ANCOVA results, $F(1, 81) = 16.06$, $p < .001$, showed that PIQ was a significant influence on performance. Once PIQ was controlled for, there were no statistically significant between-group differences, $F(3, 81) = 2.43$, $p = .079$. Therefore, the significant difference in path length between the AS and HFA groups may be accounted for by variance in intellectual functioning, rather than in actual navigational ability.

With regard to CG Arena probe trial dwell time data, the ANCOVA results, $F(1, 81)= 12.47$, $p < .001$, showed that PIQ was a significant influence on performance. Again, once PIQ was controlled for there were no statistically significant difference between-group differences, $F(3, 81) = 1.72$, $p = .169$. Again, these data show that the relatively poor performance by the HFA group on the probe trial may be accounted for by variance in intellectual functioning rather than in actual cognitive mapping ability.

With regard to ORT data, the ANCOVA results, $F(1, 80) = 2.45$, $p = .121$ showed that PIQ was not a significant influence on performance. Similarly, with regard to the ART data, the ANCOVA results, $F(1, 78) = 1.59$, $p = .211$, showed that PIQ also was not a significant influence on performance. Otherwise stated, the relatively poor performance of the HFA participants on these two tasks appears to be due to unique variation in recognition memory performance (ORT) and cognitive mapping performance (ART); variance in intellectual functioning cannot entirely account for between-group differences on this task.

Summary of results: Spatial navigation tasks. Predictions derived from WCC theory state that ASD individuals should show *impaired* performance on spatial navigation task in an unfamiliar environment, relative to typically developing controls; in contrast, predictions derived from EPF theory state that ASD individuals should show *intact* performance on such tasks relative to typically developing controls. The prediction of the EPF theory was confirmed by the current data. As predicted by the EPF theory, all the ASD participants performed similarly, relative to their matched healthy controls, on the spatial navigation task. The results of the probe trial suggested that the HFA, and possibly the PDD-NOS, participants may be finding the target by luck. However, the relatively poor performance by the HFA and PDD-NOS groups on the probe trial may be accounted for by variance in intellectual functioning rather than in actual cognitive mapping ability. Examination of the search strategies suggests that the HFA and PDD-NOS groups were using a combination of both effective and less effective strategies. There was no significant difference between the LFA and MR groups on the types of strategies used, but both these groups made use of various less effective strategies. Hence, the current data stand in contrast to the prediction made by the WCC theory, but are consistent with the predictions made by the EPF theory and with findings from previous studies of spatial navigation in ASD (see, e.g., Caron et al., 2004; Daniels, 2009; Edgin & Pennington, 2005).

DISCUSSION

There have been inconsistent findings regarding the general spatial ability, as well as the spatial navigational ability of children with autism. With regard to general spatial ability, some studies have reported that autistic children show superior performance to typically developed children (e.g., Jarrold, Gilchrist, & Bender, 2005; Jolliffe & Baron-Cohen, 1997; Mottron, Burack, Iarocci, Belleville, & Enns, 2003; Ropar & Mitchell, 2001; Shah & Frith, 1993), whereas other, mostly more recent, studies have shown that children with autism have intact but not superior performance when compared to typically developed children (e.g., Caron et al., 2003; Edgin & Pennington, 2005; Jarrold, Gilchrist, & Bender, 2005). This is an area of ongoing debate in autism research, and the results of the current study provide further information in this regard. With regard to previous studies on spatial navigation in autism, these studies have reported that autistic children show intact performance when compared to typically developing children (e.g., Caron et al, 2004; Daniels, 2009; Edgin & Pennington, 2005). This study also aimed to provide information regarding the spatial navigational ability of children with autism, and uniquely sought to provide information on the navigational search strategies of these children.

The current data was discussed with reference to the Weak Central Coherence theory (WCC; Frith, 1989) and the Enhanced Perceptual Functioning theory (EPF; proposed by Mottron & Burack, 2001; revised by Mottron, Dawson, Soulieres, Hubert, & Burack, 2006). WCC theory predicts that ASD individuals should have superior local-level processing skills and inferior global-level processing skills relative to typically developing individuals. EPF theory also predicts that ASD individuals should have superior local-level processing skills, but in contrast to WCC theory, holds that ASD individuals should have intact, but not inferior, global-level processing skills. More specifically, with regard to allocentric and egocentric spatial coding, the predictions derived from WCC theory are that individuals with ASD should have intact egocentric spatial coding (because this form of coding requires more local-level processing, participants do not need to make use of external cues) and impaired allocentric spatial coding (because this form of coding requires global-level processing). The predictions derived from EPF theory suggest that individuals with ASD should have intact egocentric and intact allocentric spatial coding. The WCC predictions, as applied to spatial navigation, state that individuals with ASD should have intact navigation in familiar environments and impaired navigation in unfamiliar environments. The EPF predictions, as applied to spatial navigation, state that individuals with ASD should have intact navigation in both familiar and unfamiliar environments. Given this background, the following sections will seek to interpret the current data in terms of whether they confirm or disconfirm predictions made by both the WCC and EPF theories, as well as the way in which they stand in relation to previously published studies.

Measures of General Spatial Ability

Overall, the results showed that children with autism have intact, but not superior general spatial ability. Specifically, the current data showed that on tasks requiring local-level processing and a detail-specific focus, such as the CEFT, BD and ROCF, the LFA and AS individuals displayed intact, but not superior general spatial abilities when compared with their respective IQ-matched control groups. These participants also did not display inferior performance to their controls on tasks of global-level processing. HFA and PDD-NOS participants, however, performed poorly on tasks requiring both local- and global-level processing.

Therefore, data from the LFA and AS groups regarding general spatial ability disconfirmed predictions made by both WCC and EPF theory. In contrast, data from the HFA and PDD-NOS groups on global-level tasks (a) confirmed the WCC theory's prediction of poor global-level processing in ASD individuals relative to typically developing controls, and (b) disconfirmed the EPF theory's prediction of intact global-level processing in ASD individuals relative to typically developing controls. These results show how important it is for both researchers and clinicians to differentiate diagnostically between individuals on the autism spectrum, as performance is not uniform.

Taken together, these results show that neither the weak central coherence theory nor the enhanced perceptual functioning theory provides a sufficient understanding and explanation of basic visuo-spatial processing in ASD populations. In previously published autism research (Jarrold, Gilchrist, & Bender, 2005; Jolliffe & Baron-Cohen, 1997; Mottron, Burack, Iarocci, Belleville, & Enns, 2003; Ropar & Mitchell, 2001; Shah & Frith, 1993), WCC theory has been used to provide a framework for understanding the superior performance of ASD participants on some visuo-spatial tasks that require local-level processing, and for their inferior performance on tasks requiring global-level processing. This formerly dominant theory has also attempted to provide a way of understanding ASD individuals' 'islets of ability'. However, results from the present study place the WCC theoretical framework into question. The current data suggests that, at best, the predictions derived from the WCC with regard to general spatial ability and local- and global-level processing are only valid for certain individuals on the spectrum.

In recent autism research (Deruelle et al., 2006; Rondan & Deruelle, 2007), the enhanced perceptual functioning model has been presented as an alternative framework to the WCC in terms of explaining cognitive functioning in autism. The primary point of disagreement between this model and the WCC model is that EPF theory suggests that individuals with autism have intact, but not superior performance on tasks requiring global-level processing.

Only part of the current data confirms predictions derived from EPF theory. The AS and LFA individuals showed intact local- and global-level processing on tasks of general spatial ability when compared with their IQ-matched controls. These results are similar to those presented by, for instance, Rondan and Deruelle (2007), who suggested that ASD individuals have intact local- and global-level processing, and that when forced to choose, they show a preference for examining objects from detail-specific perspective, but that if need be, they are able to complete tasks effectively by using a global-level perspective.

However, some of the current data also disconfirms predictions derived from EPF theory. More specifically, the HFA and PDD-NOS individuals showed relatively poor performance on both global- and local-level tasks.

In summary then, the current data demonstrate that neither WCC nor EPF theory is able to provide a complete understanding of the general spatial abilities of individuals across the autism spectrum. The data also show that performance on tasks assessing general spatial abilities is not uniform across groups of ASD participants, thus demonstrating how essential it is to differentiate between individuals on the spectrum when conducting research studies of this kind. The fact that the two theoretical frameworks do not provide a complete understanding of cognitive functioning in autism for all individuals across the spectrum again shows how these individuals are different from one other, and that they therefore should not be placed into one large group. As such, it is important for researchers and clinicians to differentiate diagnostically between individuals on the autism spectrum.

Measures of Allocentric Spatial Ability

With regard to allocentric spatial coding, results from previous studies have shown that children with autism have impaired functioning in this domain of cognitive functioning (Daniels, 2009; Pertini, 2004). Predictions derived from WCC theory state that ASD individuals should show *impaired* performance on allocentric spatial coding tasks, such as the NBMT and SPC, relative to typically developing controls; in contrast, predictions derived from EPF theory state that ASD individuals should show *intact* performance on such tasks, relative to typically developing controls.

Allocentric spatial coding involves the use of global-level processing when locating an object within the environment. Results from the Nine Box Maze Test showed that the LFA children did not have impaired allocentric spatial coding in comparison to the MR children. Otherwise stated, it appears that low-functioning autistic children do not have difficulty in using this type of spatial coding efficiently. These results disconfirm the prediction made by WCC theory regarding inferior performance of children with autism on tasks requiring global-level focus. They do however confirm the prediction made by the EPF theory regarding intact global-level processing in children with autism.

Analysis of the NBMT data from the HFA, PDD-NOS, AS, and TD groups showed, however, that children diagnosed as HFA and PDD-NOS struggled (relative to TD children) to employ allocentric spatial coding strategies. The AS children, however, had no difficulty on these tasks, and performed comparably to the TD children. This data (a) partially confirmed predictions made by WCC theory regarding inferior performance of children with autism on tasks requiring global-level processing, and (b) partially disconfirmed predictions made by EPF theory regarding intact global-level processing in children with autism. The performance by the AS group, however, confirmed the prediction made by the EPF theory.

On another task of allocentric spatial coding, the spatial place coding task (SPC), LFA, HFA, and PDD-NOS children performed more poorly than their IQ-matched controls. These results confirm predictions made by the WCC theory regarding relatively impaired global-level processing in children with autism. Again, however, AS children performed similarly to TD children, suggesting that these participants have intact, not impaired, allocentric spatial ability, thereby disconfirming the same WCC theory prediction. As with the data summarized in the previous section, these results show that it is important to distinguish diagnostically between individuals on the autism spectrum, as their cognitive performance is not uniform, even relative to IQ-matched controls.

With regard to predictions made by EPF theory regarding allocentric spatial coding, the performance by the LFA and AS groups on the NBMT, and the AS groups performance on the spatial place coding task (SPC), confirm the prediction made by the EPF theory regarding intact global-level processing in children with autism. The performance, however, by the HFA and PDD-NOS groups on the NBMT and by the LFA, HFA and PDD-NOS groups on the spatial place coding task (SPC), disconfirm the prediction made by the EPF theory regarding intact global-level processing in children with autism.

The performance of the LFA participants on the two separate tasks examining allocentric spatial coding provided conflicting results. One possible explanation for this discrepancy is that the NBMT has short and simple instructions therefore eliminating the possibility of the LFA individuals becoming distracted or confused. The instructions on the SPC, however, were more complex and drawn out. It is essential for the individuals to understand the complete instructions as well as remember the exact order in which the task should be carried out to ensure successful completion of the task. The LFA participants were however often easily distracted during testing, creating the need for shorter sessions as well as shorter instructions. Therefore the difficulty in following longer, more complex instructions may have influenced the LFA individuals' performance on the SPC task, as these individuals possibly did not remember the full instructions causing the misplacement of the object on the cardboard.

In summary, the current data, with regard to allocentric spatial coding, provides evidence that neither WCC nor EPF theory can provide a framework for predicting and understanding the cognitive strengths and weaknesses of individuals across the autism spectrum. Hence, the results presented here suggest that both theories fall short of their aims.

Measures of Egocentric Spatial Ability

With regard to egocentric spatial coding, results from previous studies have shown that children with autism have intact functioning in this domain of cognitive functioning (Daniels, 2009; Pertini, 2004). Predictions derived from both the WCC and EPF theories state that ASD individuals should show *intact* performance on egocentric spatial coding tasks, such as the SRL and CG Arena visible-target trials, relative to typically developing controls.

On the spatial response learning task (SRL), LFA children showed impaired performance relative to their MR counterparts. One interpretation of this finding, of course, is that the egocentric spatial coding abilities of the LFA children are relatively impaired. An alternative account, however, is that the statistically significant difference can be explained by the fact that sensory difficulties present in the LFA children but not in the MR children, played a role in task outcome. Specifically, most LFA children did not like having to close their eyes during the task. Having to close their eyes often resulted in a feeling of discomfort and anxiousness for these LFA individuals , often leading to them trying to open their eyes or remove the examiners hand from their eyes. As explained in the Methods section, when completing the SRL task, participants are required to close their eyes to ensure that they are able to place the object on the cardboard in the correct position, without the use of external visual cues. Having to close their eyes, or have their eyes closed for them by the examiner, may have negatively affected the way in which the task was performed by these individuals. Closing their eyes made the children feel uncomfortable and resultantly, this distracted them from the task at hand. This distraction may have lead to poor concentration during the task. Therefore, this action affected the children's ability to complete the task to the best of their ability. Therefore, it may be disruptions due to these sensory difficulties, rather than poor egocentric spatial coding, that led to the relatively poor performance by LFA participants on this task.

With regard to data from the HFA, AS, PDD-NOS, and TD groups, the results showed that the HFA group struggled (relative to TD children) to employ egocentric spatial coding strategies on the SRL task. The poor performance by the HFA group on this task suggests relatively impaired egocentric spatial ability in those children. Again, however, there is an alternative explanation: some HFA participants also presented with sensory difficulties and felt uncomfortable closing their eyes or having their eyes closed for them by the examiners. In the same way as for the LFA participants with such task disruption, these sensory difficulties may have played a role in the way these participants completed the task, and may therefore have affected the results obtained.

Clearly, then, these results disconfirm predictions made by both the WCC and EPF theories. The performance by both the LFA and HFA individuals on the SRL task suggests impaired egocentric spatial coding, which disconfirms the predictions by both the WCC and EPF theory and is in contrast to previous findings on egocentric spatial coding (Daniels, 2009; Pertini, 2009). However, the performance by the AS and PDD-NOS groups on the SRL task suggests intact egocentric spatial coding in these groups. These results confirm the predictions by both the WCC and EPF theory.

The task that participants had to complete on the CG Arena visible-target trials also provided a measure of the egocentric spatial coding abilities. Participants were required to locate a visible target within the arena, and could do so without having to make use of external cues or landmarks—they could simply move to the target using pertinent proximal visual cues with reference to their own position in the arena. Of note here is that the sensory difficulties mentioned above played no role in CG Arena task performance.

On the set of visible-target trials, LFA participants had similar mean path lengths from start position to target as MR participants, and HFA participants had similar mean path lengths to AS, PDD-NOS, and TD participants. Hence, it appears that ASD participants displayed intact egocentric spatial coding ability. The results of the visible-target trials confirm predictions made by both the WCC and EPF theories.

This inconsistency between the two tasks assessing egocentric spatial coding suggests that the relatively poor performance by HFA and LFA participants on the SRL task might be accounted for by the sensory difficulties experienced by some of the children in those groups during the task, rather than by actual impairment in egocentric spatial coding. Clearly, then, there is a need for further examination into the egocentric spatial coding ability of ASD children, and especially LFA and HFA individuals, using tasks more suitable (i.e., tasks that will not be confounded by sensory difficulties) than the SRL task.

Although the current set of results should be interpreted with caution for the reasons mentioned above, performance on the CG Arena visible-target trials was not plagued by any sensory difficulties, and therefore might be regarded as providing more accurate results regarding the egocentric spatial coding abilities of these individuals. If we take weight these results more heavily than those from the SRL task, then there is the suggestion that the ASD individuals showed intact egocentric spatial ability, and hence predictions made by both the WCC and EPF theories are confirmed.

Measures of Spatial Navigational Abilities

With regard to spatial navigation, results from previous studies have shown that children with autism have intact functioning in this domain of cognitive functioning (Caron et al., 2004; Daniels, 2009; Edgin & Pennington, 2005). Predictions derived from WCC theory state that ASD individuals should show *impaired* performance on spatial navigation task in an unfamiliar environment, relative to typically developing controls. In contrast, predictions derived from EPF theory state that ASD individuals should show *intact* performance on such tasks, relative to typically developing controls.

Successful navigation on the CG invisible-target trials (i.e., locating and relocating the invisible target, starting from different positions each time) requires intact allocentric spatial coding ability. That is to say, participants have to use the distal visual cues (pictures on the walls of the Arena) to help them remember where the target is hidden, and how to get to it as quickly and efficiently as possible. The performance by the LFA, HFA and PDD-NOS participants on the allocentric tasks (NBMT and SPC), showed that these individuals had difficulty employing allocentric spatial coding, suggesting that the navigational abilities of the LFA, HFA and PDD-NOS participants, within the arena, should be impaired.

All participants showed intact cognitive map-based spatial navigation in a novel environment. These results therefore disconfirm predictions derived from WCC theory, but confirm predictions derived from EPF theory, about map-based navigation in ASD individuals. ASD individuals did not display impaired map-based navigation in an unfamiliar environment, but rather performed in a manner comparable to their IQ-matched controls. That is to say, the ASD participants located and relocated the target the same number of times as the controls, and used similar path lengths to reach the target.

A particular point of interest with regard to the CG Arena data was the statistically significant difference between the HFA and AS participants in terms of mean path length on the invisible-target trials. By themselves, this data, might suggest that AS individuals have superior allocentric spatial navigational abilities to HFA participants. However, once PIQ was controlled for, there was no remaining significant difference between the two groups, suggesting that the difference was due to variations in intellectual functioning rather than differing navigational abilities. To further emphasize this point, there were no statistically significant differences between the HFA and TD group, or between the AS and the TD group, in mean path length on the invisible-target trials.

With regard to the CG Arena probe trial data, PDD-NOS and HFA participants performed more poorly than TD participants (i.e., they spent less time searching the quadrant in which the target had been located on the set of invisible-target trials). This data, then, suggests that either the HFA and PDD-NOS participants were finding the target by luck on the invisible-target trials, or that their cognitive maps are less robust than those of the TD participants, or that they have less persistence of search than TD participants. Fortunately, I did not have to find the best interpretation of these between-group differences. Once PIQ was controlled for, those differences disappeared, and one might therefore conclude that the relatively poor performance by the HFA and PDD-NOS participants on the probe trial could be accounted for by the fact that their general intellectual functioning was poor relative to TD and AS participants.

Even though PIQ variance could account for many of the between-group performance differences on the various CG Arena outcome variables, it was still of interest to explore the spatial search strategies used by participants on the invisible-target trials. Regardless of whether differences in search strategies emerged from PIQ variance or actual variance in spatial cognitive ability, or some combination of the two, it is of practical, clinical, and research interest to know whether ASD participants adopt different search strategies to their

IQ-matched controls, and to thereby understand more about their spatial navigational abilities.

Analyses of search strategy data showed that there was no statistically significant difference between the types of strategies used by the LFA and MR participants. Interestingly, however, participants in both of these groups made primary use of the less efficient strategies, such as Thigmotaxis, while navigating the environment.

With regard to search strategies in the HFA, AS, PDD-NOS, and TD groups, there were statistically significant between-group differences. Participants in the AS and TD groups tended to use the most effective strategy (Visual Scan). This strategy is considered the most effective because it is the most efficient. Typically, individuals stand in one area, scan the room for pertinent visual cues and landmarks, and then head directly towards the target. They do not waste time and energy by moving around the room continuously searching for the target. Most HFA and PDD-NOS participants also made frequent use of the Visual Scan strategy, but only a small number of these participants made use of other, less effective, strategies, such as Thigmotaxis, Circling, and Other/None. These strategies are less efficient because instead of using the visual cues and external landmarks (such as the pictures in the arena) during navigation, individuals rather walk round in circles or make use of the wall when finding the target.

The statistically significant between-group difference with regard to search strategies used during navigation, and the lack of such differences on the actual path length and targets located measures, possibly explains why participants could navigate effectively even though their performance on allocentric spatial coding tasks was not intact: They simply used alternative strategies to locate and relocate the invisible target.

In summary, the analysis of search strategies helped to provide an explanation as to how individuals, who might have impaired allocentric spatial coding ability, navigate to a hidden target in a novel environment successfully. The combination of different strategies, both efficient and poor, may explain why and how such individuals can locate and relocate the target, even in the absence of an optimal cognitive mapping ability. Even though the Thigmotaxis, Circling and Other/None strategy are less efficient than the Visual Scan strategy, they still enable participants to locate and relocate the target, and to thus, on the surface, present with largely intact spatial navigational abilities. The intact spatial navigational abilities of the ASD individuals within this study are consistent with previous findings (Caron et al., 2004; Daniels, 2009; Edgin & Pennington, 2005). There are, however, no published studies focusing on spatial search strategies in autism.

The types of search strategies used by ASD individuals, and the reasons for their use, still require further examination. For instance, the current data shows that LFA, HFA, and PDD-NOS children tend to make use of a variety of strategies, and often do so in combination (i.e., they switch strategies from trial to trial, and sometimes within trial). Furthermore, the participants in this study also made use of search strategies that were not able to be classified into one of the four categories previously defined by Kallai et al. (2005). This piece of data shows the need for further clarification into what types of strategies are used, not only by ASD children, but by children in general: Kallai and colleagues based their taxonomy of strategies on data provided by undergraduate students. To my knowledge, there are no published papers focusing on the types of search strategies used by typically developing children, or by children with any kind of developmental disorder. Given that neural development between infancy and adolescence has a major effect on spatial navigation performance differences in children of different ages (see, e.g., Laurance, Learmonth, Nadel, & Jacobs, 2003; Newcombe, Uttal, & Sauter, 2010), a research focus on how search strategies change as children age, and on whether developmentally-disabled children are ever able to use the same efficient search strategies as typically developing children, might be a fruitful avenue of inquiry. The study by Laurance, Learmonth, Nadel, and Jacobs (2003) and by Newcombe, Uttal and Sauter (2010) demonstrate how place learning in a navigation task progressively develops throughout childhood, typically starting from ages 3-4 years to roughly ages 9-10 years.

Results from the ORT and ART analyses showed that LFA participants performed no differently than MR participants on these tasks of, respectively, recognition memory and spatial memory. In contrast, however, HFA participants performed more poorly than TD participants on the ORT: they had more difficulty identifying which of the pictures presented to them post-Arena had been in the Arena and which had not. This piece of data might suggest that the HFA participants were not paying as much attention to all of the distal visual cues while trying to locate the target within the arena. On the ART task, however, HFA participants performed just as well as the TD participants: they were able to reconstruct the arena when presented with the stimulus items, suggesting that their cognitive maps were intact.

These results are conflicting, as the ORT data suggest that the HFA participants have difficulty remembering the correct pictures from the room, whereas ART data suggest that they do actually remember the pictures, and are able to put them in the correct position. An explanation for this discrepancy may be found in the way in which the tasks were administered. On the ART task, the participants were given the layout of the arena with the correct pictures (and no distracter pictures), which may have helped the individuals better recall the room. Furthermore, the template layout of the Arena may have helped remind the participants what the room looked like, therefore allowing better recall as to where the pictures were located in the room. The ORT, on the other hand, only presented the pictures (with various distracter pictures) without any other cues to help the participant. This difference between types of task requirements (recognition versus cued recall) may explain why the ASD individuals performed better on the ART task than on the ORT task.

Limitations and Directions for Future Research

There are numerous limitations to the current study; some of these are discussed in detail below. Also discussed are the ways in which future research studies might address those limitations.

Participants. In the current study, the participants were matched on the major demographic variables of age, sex, and socioeconomic status. Ensuring that they were matched on all demographic variables proved to be a difficult task, however; there were significant between-group differences in terms of race, home language, and handedness. As could be expected, the larger the sample size, the more difficult it is to match groups on all sociodemographic variables, and so the matching problem found in this study was considered to not be uncommon.

There are several points to be made in mitigation of the between-group demographic differences in the current study. With regard to race, no studies have been found showing that race has an effect on cognitive functioning in ASD. Therefore, the currently observed between-groups difference in terms of race should have had no affect on the results reported here.

With regard to home language, there was also a statistically significant difference between the HFA, AS, PDD-NOS, and TD groups. English was the most commonly spoken home language across all groups, and especially within the AS and PDD-NOS groups. However, within the other groups, there was good representation of various other home languages (e.g., many of the TD children spoke Afrikaans as a home language, and several children in the HFA groups had Zulu, Sotho, and Xhosa as their home language). Although our research group could have decided to recruit only, for instance, children with a home language of English, it was decided to use children with different home languages, so as to be able to generalize the results as much as possible to the broader South African population. If only English home language participants were included in the study, not only would the sample size have been greatly reduced, but the power to generalize the results would have been compromised.

Tolerance of the test procedure, and ability to understand test requirements and instructions, are unlikely to have been affected by these differences in home language. All participants attended schools where the medium of instruction was either English or Afrikaans, and as such, they were all able to understand the test instructions and the test battery. Once testing commenced, if a child was unable to complete a task or comprehend an instruction due to language differences, the testing session was concluded and the participant was excluded from the study.

Another limitation of the current study was the small sample size of the LFA group. As noted earlier, LFA individuals are frequently excluded from participation in such research studies; hence, one of the main aims of the current study was to include a group of LFA participants so as to investigate the question of whether theories designed to explain cognitive functioning in ASD could truly be applied to the entire spectrum of individuals. Unfortunately, however, many of the LFA children that the research group attempted to recruit were unable to understand even basic commands and instructions, and therefore were not able to participate. Even if the child was able to understand basic commands and instructions, he or she might not have been able to comprehend the more complex ones (e.g., the task instructions associated with the CG Arena). Therefore, obtaining a large number of LFA participants was a most difficult obstacle, and it is highly likely that future research endeavours will face the same challenges.

Diagnosis. A major issue in the current study, as in many autism research studies, involved the diagnosis of children with autism. Children within the study were diagnosed by independent clinicians. Given that these independent clinicians were not all equally experienced at differential diagnosis within ASD, and the considerable disagreement between clinicians regarding diagnostic categories, there have to be some questions raised about whether group assignment was perfectly accurate.

Witwer and Lecavalier (2008), in their review, note that this diagnostic issue arises in many different autism research studies. It is recommended that future research in this field should therefore focus on ensuring that all participants have been diagnosed using the same tool. Furthermore, researchers should ensure that whoever administers the diagnostic tool has adequate training therein, and that standardized diagnostic procedures are followed for each potential participant.

The Autism Diagnostic Observation Schedule (ADOS; Lord et al., 1989) is a diagnostic tool that encourages the implementation of just such design strategies. The ADOS is semi-structured instrument used to elicit spontaneous behaviour within a standardised context during an assessment. This measure, used in conjunction with the Autism Diagnostic Interview-Revised (ADI-R), is regarded as the best method for diagnosing individuals with autism (Oosterling et al., 2010). The ADOS includes four modules to ensure individuals at different developmental and language levels can be assessed. The person administering the ADOS has a score sheet for immediate coding, and is encouraged to videotape the administration as well, thus allowing for a more detailed analysis later on (Lord et al., 2000). The ADOS has been shown to be a valid and reliable diagnostic instrument, and has good predictive value for autism spectrum disorders (Bastiaansen et al., 2010; Tomanik et al., 2007). The extensive training required to become competent in administering the ADOS ensures that all clinicians with such training will be equally experienced in diagnosing individuals on the spectrum, and that they will all be using the same standardised procedures.

Another major limitation of the study, related to the diagnostic issue, was the fact that many of the ASD participants presented with a comorbid diagnosis of attention-deficit/hyperactivity disorder (ADHD). This comorbidity is not surprising; many children on the autism spectrum also present with ADHD (Goldstein & Schwebach, 2004). Hence, in research studies of this kind, it is extremely difficult to find participants with a ‘pure’ autism diagnosis. Future research should perhaps include an ADHD control group to examine the performance of those children on the various tasks of spatial cognition.

Tasks. Another potential limitation of this study was the complexity of some of the task instructions. Obviously, overly complex task instructions can be a problem throughout the testing sessions, as children might struggle to understand them, thus affecting the way in which the task is completed. For example, on the Rey-Osterrieth Complex Figure (ROCF) task, participants were asked to copy the drawing presented to them. This is a simple instruction, and it was typically understood by all, including the low-functioning individuals. However, after the drawing had been completed and removed from the individual’s sight, the participants were asked to redraw the same figure as best they could from their memory. Many of the lower-functioning participants struggled to understand this instruction, possibly because they did not understand the word ‘memory’. Then, perhaps because they did not understand what was required of them, many of these participants went on to draw pictures other than the complex figure. In short, this lack of understanding of what is, for typically developing children, a relatively simple instruction often led to poor performance by some lower-functioning individuals on both the immediate delay and the 30-minute delay ROCF trials.

Another example of complex instructions affecting the performance of certain participants occurred in the administration of the Children's Embedded Figures Task (CEFT). On this task, participants were required to locate an object that was the same size and shape as the cut-out presented to them. Again, some lower-functioning participants struggled to understand these instructions and were thus often unable to locate the correct shape within the picture. For example, on the first few CEFT trials, participants were required to find a triangle hidden in the picture that was the same size and shape of the cut-out shown in the practice rounds. Often, lower-functioning participants did not understand the full instruction, and would point out an incorrect triangle. Therefore, they would understand that they needed to find a triangle, but they would select a triangle of the wrong size or shape. So, at least some of the poor performance on the CEFT by certain lower-functioning individuals may thus be attributed to the complexity of the task instructions.

Although most of the tests used in the current study have been used previously in studies of ASD children (Daniels, 2009; Edgin & Pennington, 2005; Pertini, 2004), almost none of them have been used in studies of LFA and MR children, and some of them have not been used in children as young as some of those who participated in this study. Although our research team made the age-appropriate adjustments, and took rigorous steps to ensure that the tasks were explained in great detail to the participants, it is likely (judging by the difficulties we experienced) that several of the task instructions will need to be simplified even further in future studies.

With regard to actual task complexity, one limitation of the present study was that previous familiarity with computers and computer games was not adequately controlled for. Even though there was no significant between-group difference on a self-report measure of how much time participants spent on a computer (the *Frequently* category was daily or weekly use, the *Sometimes* category was monthly or yearly use, and the *Never* category was never used a computer before), many of the LFA and MR individuals, and some of the HFA individuals, fell within the Never or Sometimes category. A relative lack of computer familiarity and experience by those individuals within may have affected their performance on the CG Arena tasks, for instance.

Nonetheless, on tasks such as the CG Arena, it might have been valuable to allow participants, particularly those with little previous computer or gaming experience or those with less-developed motor skills, several practice trials before beginning actual task administration.

Summary and Conclusion

The results of this study provide findings disconfirming predictions made by two of primary theories used to explain cognitive functioning in autism- the weak central coherence theory and the enhanced perceptual functioning theory. The current data showed that these theories cannot completely explain the patterns of strengths and weakness in spatial cognitive ability across the autism spectrum, and that each therefore needs to be adjusted and refined (or even replaced by a more viable theory) in order to be applicable to the ASD population.

One of the most important conclusions drawn from the results of the current study is that it is extremely important for clinicians and researchers to distinguish diagnostically between individuals on the autism spectrum, as the performance of different groups on the study tasks were not uniform. In particular, there were several differences in performance between HFA and AS individuals; hence, research studies that place such individuals into one group and label it as “the autism group” or “the high-functioning autism group” are doing the field of autism research a disservice.

Another important conclusion drawn from the current study is that it is important to include LFA individuals in studies of ASD cognitive functioning. The patterns of performance shown by LFA individuals were sufficiently unique and interesting to warrant this statement. Furthermore, the current study showed that using an IQ-matched control group for the LFA group is a viable proposition and an appropriate step to take.

One of the major contributions this study made was to add to the knowledge base about wayfinding in ASD individuals, particularly with regard to search strategies during navigation. Results suggested that, regardless of diagnosis, ASD individuals showed reasonably intact spatial navigational abilities. These results were consistent with previous studies regarding spatial navigation in ASD, and confirmed the prediction derived from the EPF theory. These results did, however, not confirm the prediction derived from the WCC theory. The analysis of search strategies, however, showed that LFA, MR, HFA, and PDD-NOS participants tended to use less efficient strategies in their attempts to locate and relocate a hidden target placed in a fixed position across trials. There have been no previous studies examining the navigational search strategies of individuals with ASD (or, indeed, of the development of increasingly efficient search strategies throughout childhood and adolescence), and the results of the current study have shown the need for further examination into these questions. Understanding how ASD individuals navigate their environments, and under which circumstances they might choose to use particular kinds of search strategies, will help clinicians, researchers, and parents understand how ASD individuals see the world around them.

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Appendix A

DSM-IV-TR 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 gesture 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, non-functional routines or rituals
    c. stereotyped and repetitive motor manners (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 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 of focus
    2. apparently inflexible adherence to specific, non-functional routines or rituals
    3. stereotyped and repetitive motor mannerisms (e.g., hand or finger flapping or twisting, or complex whole-body 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 general delay in language (e.g., single words used by age 2 years, communicative phrases used by age 3 years).

E. 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.

F. Criteria are not met for another specific Pervasive Developmental Disorder or Schizophrenia.

Appendix C

DSM-IV Diagnostic Criteria for Pervasive Developmental Disorder Not Otherwise Specified

This category should be used when there is a severe and pervasive impairment in the development of reciprocal social interaction associated with impairment in either verbal or nonverbal communication skills or with the presence of stereotyped behaviour, interests, and activities, but the criteria are not met for a specific Pervasive Developmental Disorder, Schizophrenia, Schizotypal Personality Disorder, or Avoidant Personality Disorder. For example, this category includes "atypical autism" - presentations that do not meet the criteria for Autistic Disorder because of late age at onset, atypical symptomatology, or subthreshold symptomatology, or all of these.

APPENDIX D

GLOSSARY

Allocentric Referencing. The viewing of an object in relation to external landmarks and to other external objects, and is independent of the relation between the self and that object.

Central Coherence. The ability of a person to view and process information as a whole.

Circling strategy. This strategy is defined by the participant following a circular path close to the wall of the arena.

Cognitive map. A mental representation of the environment that an individual uses as a guide and reference system to navigate within the environment.

Egocentric Referencing. The viewing of an object in relation to the self rather than in relation to external landmarks or to other external objects.

Enfilading strategy. This strategy involves small position corrections and non-strategic motions.

Enhanced Perceptual Functioning model. This theory states that ASD individuals have superior local-level processing skills, as well as intact global-level processing skills.

Route Knowledge. Knowledge gained from an internal perspective and involves information about the layout of an environment from the perspective of the individual.

Survey Knowledge. Knowledge gained from an external perspective (e.g., a physical map of the environment, or an aerial view of it), and it involves information about the global layout of an environment.

Thigmotaxis strategy. This strategy is defined by the participant following a circular path close to the wall of the arena.

Visual Scan strategy. This strategy is used when an individual stands in a fixed position and turns around to examine the arena’s distal cues.

Weak Central Coherence. The processing of information from a detail-specific perspective, therefore focusing on a local rather than global level.

Appendix E

DSM-IV Diagnostic Criteria for Mental Retardation

Definition

A developmental condition that is characterized by significantly lower then average level of general intellectual functioning. Failure to develop cognitive abilities and achieve an intelligence level that would be appropriate for their age group.

Mild Mental Retardation About 85% of persons that are Mental Retarded fall into this group.	IQ level 50-55 up to about 70
Moderate Mental Retardation About 10% of persons that are Mental Retarded fall into this group.	IQ level 35-40 to 50-55
Sever Mental Retardation About 3% to 4% of persons that are Mental Retarded fall into this group.	IQ level 20-25 to 35-40
Profound Mental Retardation About 1% to 2% of persons that are Mental Retarded fall into this group.	IQ level below 20 or 25

Mental Retardation Severity Unspecified: When there is a "STRONG" presumption of Mental Retardation but standard test can not be used to determine level of impairment.

Criteria

1. Intellectual functioning significantly below average. IQs of about 70 or lower in person who can take an IQ test. Clinical judgment must be use on those who can not take an IQ test.

2. Impairments or deficits for that age group in functioning in at last two of the following areas:

1. Communication.
2. Health.
3. Leisure time.
4. Safety.
5. School.
6. Self-care.
7. Social.
8. Taking care of a home.
9. Work.

3. The onset of impairment must be before the age of eighteen.

Appendix F

Participant no.: _______ Date: ______

DEMOGRAPHIC QUESTIONNAIRE

E. **Child's Information:**

1. Name: _____________________
2. Age: ______
3. Date of Birth (dd/mm/yy): ___________
4. Sex (circle one): Male Female
5. Ethnicity: White Black Indian Coloured Asian
   Other If other please specify: ____________
6. Home Language: ___________
7. Handedness (circle one): Left Right Ambidextrous
8. Number of siblings: ___________
9. Number of **older** siblings: ___________
10. How often does your child use a computer?

    Never ___ A few times a year ___ Once a month ___ Once a week ___ Every day _

11. Has your child ever experienced a head injury? (e.g., being hit on the head with an object and losing consciousness as a result)

    YES NO

    If yes, please give details:

    ____

12. Has your child ever experienced any of the following medical conditions:

    a. Neurological problems YES NO

    If yes, please specify:

    ____

    b. Depression YES NO

    ____

If yes, please specify:

---

c. Memory problems YES NO

If yes, please specify:

---

d. Problems with your vision YES NO

If yes, please specify:

---

e. Problems with your hearing YES NO

If yes, please specify:

---

f. Is he/she currently taking any prescription medication? YES NO

If yes, what medication(s)?

---

11. Has your child ever been diagnosed with a social disorder such as conduct disorder or oppositional defiant disorder (ODD)? YES NO

If yes, please specify:

---

12. Has your child ever had a communication disorder? (For example: Having problems with understanding or producing speech, slow vocabulary development, difficulties recalling words or problems with producing sentences appropriate for his/her age.)

YES NO

If yes, please specify:

---

13. Has your child ever been diagnosed with a pervasive developmental disorder such as autism, Asperger's syndrome, Rett's disorder or childhood disintegrative disorder?

YES NO

If yes, please specify:

____

14. Has your child ever experienced learning difficulties such as dyslexia or attention-deficit / hyperactivity disorder (ADD/ ADHD)?

YES NO

If yes, please specify:

____

B. Parent Information:

E. What is the total yearly income of the household in which you live? (Circle one):
[NOTE: This should be household income, not personal income.]

Less than R80 000	R80 001 – R130 000	R130 001 – R180 000
R180 001 – R230 000	R230 001 – R300 000	More than R300 001

2. Education (highest degree or grade completed) of mother: ________________________

3. Education (highest degree or grade completed) of father: __________________________

4. Highest occupational level of mother: (The best job you've had, not necessarily in terms of job satisfaction or pay, but rather in terms of things like prestige or social status attached to job.) ____

5. Highest occupational level of father: (The best job you've had, not necessarily in terms of job satisfaction or pay, but rather in terms of things like prestige or social status attached to job.) ____

APPENDIX G

Consent Form
Way-Finding in Autism Spectrum Disorders

1. **Invitation and Purpose**

Your child is invited to take part in a research study about wayfinding in autism spectrum disorder. We are researchers from the Department of Psychology at the University of Cape Town. The study aims to understand better how children diagnosed with an Autism Spectrum Disorder (ASD) learn and remember aspects of the space around them compared to Mentally Challenged and Typically Developing children of the same age. Approximately 150 children will participate in this study.

2. **Procedures**

If you decide to allow your child to take part in this study, we will ask them to take complete a series of pencil-and-paper tests as well as a computer-based test. The tests will assess your child's general intellectual functioning, their general spatial abilities, and their spatial navigational abilities. There will be two sessions and each session will take about 60-90 minutes. You, another caregiver, or a teacher may be present at the testing sessions. Your child will be allowed to take breaks whenever requested during the sessions.

3. **Risks, Discomforts & Inconveniences**

There will be minimal risk involved in the research and your child will not be asked to perform any potentially harmful tasks. The only possible risk is that your child may feel uncomfortable or become fatigued during the testing. If they do they will be allowed to take a break. They may also withdraw from the tasks at anytime. At the end of the study general feedback will be provided.

4. **Benefits**

The information from this study may help improve our understanding of autism spectrum disorders, particularly with regard to general spatial abilities and spatial navigational abilities in individuals with autism spectrum disorders.

5. **Privacy and Confidentiality**

Information collected during each session will be stored in locked filing cabinets or in computers with security passwords. Only certain people have the right to review these research records. These people include the researchers for this study and certain University of Cape Town officials. All the sessions will be conducted in a private room at the school.

6. **Money Matters**

Participating in this study will not cost you or your child anything. You or your child will also receive no compensation for taking part in this study.

7. **Questions**

If you have questions or concerns about the study please contact the principal investigator Kevin G. F. Thomas, PhD: (office) 021-650-4608 (email) Kevin.Thomas@uct.ac.za or Natalia M. Ing (cell) 082-663-7028 (email) Natalia.Ing@uct.ac.za.

Consent Form

The study has been explained to me, and my questions have been answered.

I understand that participation in this study is voluntary, and that I may withdraw my child at any point.

I understand that my child will not be identified except by an initial, and that this anonymity will be maintained throughout the study and when the research is published.

I consent to allow my child to participate in this study.

Child's name ____
Signature of parent/guardian ___________________________
Date ____

I have explained the study to the participant, and in my opinion s/he understands that participation is voluntary and is able to give informed consent.

Researcher ____
Signature ____
Date ____

Use of Samples/Data for Future Research

With your permission, we would like to store the unused parts of your child's tests for use in future research. This is your choice entirely and you are free to say no and your child will still be able to take part in the study. Please check the boxes that apply to your choice:

I do <u>not</u> want my child's samples to be used for any future research. ___

You may use my child's samples for any future research about spatial navigation. ___

Please indicate below if you would like to be notified of future research projects conducted 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 I or my child might participate in the future.

Method of contact:

Phone number: ______________________________
Cell phone number: ______________________________
E-mail address: ______________________________
Mailing address: ______________________________
____
____

APPENDIX H

Assent Form

Wayfinding in autism spectrum disorders

Hello! My name is Natalia Ing. I'm here for a study on behalf of the University of Cape Town.

We're working with children from schools within the Western Cape to gather information about how children learn and remember aspects of the space around them. Therefore we are interested in how children find and remember where things are within an environment. The information gathered will be used to help us better understand how children are finding their way around an environment.

We would like to play some games with you that will take place over two sessions with each session lasting about 90 minutes. You may take a break at anytime during the games. I would like to do them by yourself, but if you would like, you can ask for a parent, guardian or teacher to be present at any time. I would like to do your best in all of the games.

If you feel tired or uncomfortable during any of the games you may stop at any time. You do not have to continue playing if you don't want to.

If you decide to participate in this study, you will have the chance to help us better understand the wayfinding abilities in children.

Remember, you do not have to take part in this study if you do not want to. If you do decide to take part in this study but change your mind later, you may stop participating and no one will be cross with you.

If you agree to take part in this study, everything will be kept confidential. That means that all your information will be kept private between you and me and only people involved in this study and certain people from the University of Cape Town will see this information.

Do you have any questions about what was just mentioned? If you think of any questions in the future, you can reach me at 082 663 7028.

Would you like to participate in the research? If so, how would you like to participate?

Date: ______________________

Child's Name/Agreement: ______________________________

Parent's/Guardian's Agreement: ________________________

Researcher’s Signature: ________________________________