This electronic thesis or dissertation has been downloaded from the King's Research Portal at https://kclpure.kcl.ac.uk/portal/

Cognitive mechanisms underlying savant skills in autism

Wallace, Gregory Lawrence

The copyright of this thesis rests with the author and no quotation from it or information derived from it may be published without proper acknowledgement.

END USER LICENCE AGREEMENT

Unless another licence is stated on the immediately following page this work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International licence. https://creativecommons.org/licenses/by-nc-nd/4.0/

You are free to copy, distribute and transmit the work

Under the following conditions:

- Attribution: You must attribute the work in the manner specified by the author (but not in any way that suggests that they endorse you or your use of the work).
- Non Commercial: You may not use this work for commercial purposes.
- No Derivative Works - You may not alter, transform, or build upon this work.

Any of these conditions can be waived if you receive permission from the author. Your fair dealings and other rights are in no way affected by the above.

Take down policy

If you believe that this document breaches copyright please contact librarypure@kcl.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.

Download date: 16. Jan. 2025

COGNITIVE MECHANISMS UNDERLYING SAVANT SKILLS IN AUTISM SPECTRUM DISORDERS

Gregory Lawrence Wallace

Institute of Psychiatry

King's College London

Thesis submitted for the degree of
Doctor of Philosophy

University of London

2006

Prepared under the supervision of
Francesca Happé and
Pamela Heaton

ACKNOWLEDGEMENTS

So many individuals enabled me to complete this work, so it is only fitting that I take a moment to thank some of them. First of all, I would like to thank the numerous participants and their families/caretakers for taking the time to work with me and for their willingness to participate in this research. Similarly, I would like to give my whole-hearted thanks to the schools and their staff for taking the time and effort to help me in recruiting participants and providing space for testing.

I am especially indebted to Dr. Francesca Happé for being generous with her time and intellectual support and for being so patient and understanding during this arduous process. Her guidance and consistent encouragement were greatly appreciated. Dr. Pam Heaton also deserves many thanks for her steadfast and positive support.

Also, I should thank a very giving group of colleagues and friends: Rhonda for intellectual discussion, technical assistance, and any other form of generosity one can think of as we went through this trying process together; Essi for overall generosity and sweetness, for reading selected chapters, and for pushing me to finish this project; John for much assistance and productive conversation regarding research design and task development; Gwyn and Judy with much technical assistance and generosity with their time and expertise during the final phases of the write-up; many other individuals for their general encouragement during this process including, Rebecca, Alessandra, Alice, Naomi, Eva, Sara, Louise, and Julia; and Jay, Alex, and many others at the NIH for their constant support while this thesis was being completed.

Finally, I want to thank Jeremy for unwavering support and patience during this entire process. Putting up with me is difficult enough; the added stress from trying to complete a thesis only reinforces how supportive a partner he has been. I also want to express my appreciation to my Mother, Father, and Derrick for their love and encouragement as well as their patience with me during the graduate school process that I know they thought would never end!

ABSTRACT

This thesis aimed to investigate possible cognitive underpinnings of savant skills in autism spectrum disorders (ASD). Since savant skills are overrepresented amongst individuals with ASD, several cognitive functions thought to be intact or enhanced in these individuals were hypothesised to contribute to savant skill development. In particular, central coherence, implicit learning, perceptual functioning, and information processing speed were assessed in a group of nonsavant children with ASD (n=28), age, IQ, and gender (group-wise) matched controls (n=28), a group of typically developing children (n=64), and finally a series of four savants with ASD.

Consistent with previous reports, weak central coherence, intact implicit learning and information processing speed, and particularly good ability to reproduce a time window were shown in both savant and nonsavant individuals with ASD. Savants also showed indications of good memory and idiosyncratic sensory functioning.

As predicted, there was evidence that information processing speed was IQ independent in ASD whereas it was significantly related to IQ in both comparison groups. There was also preliminary indication, via correlations and subgroup analyses, of cross modal central coherence, particularly within the ASD group. A "gateway model", in which certain cognitive functions need to be intact (or superior) in order for individuals (especially those with ASD) to develop savant skills, was proposed to account for these findings. The present findings are preliminary in nature but provide indications that certain cognitive functions more characteristic of the cognitive profile in ASD may be necessary but insufficient for savant skill development.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1: Autism Overview

The following chapter serves to introduce the ever-growing body of work devoted to autism research. This chapter is not intended to be exhaustive, but rather to serve as background to the studies presented in this thesis; therefore, it is slanted particularly towards considering cognitive accounts of autism. For more exhaustive coverage, the reader is directed to recent comprehensive reviews (e.g., Bailey, Phillips, & Rutter, 1996; Volkmar, Lord, Bailey, Schultz, & Klin, 2004).

1.1 Diagnosis and Symptoms

Autism is a biologically based but behaviourally defined developmental disorder primarily affecting the areas of social interaction, communication, and flexibility of behaviour. Current diagnostic conceptualisation dictates that autism or autistic disorder (previously referred to as classical autism or infantile autism) is but one condition, which occurs along a spectrum of disorders (Gillberg, 1990; Wing & Gould, 1979), sometimes referred to as autism spectrum disorders (ASD) or pervasive developmental disorders. According to the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV; APA, 1994), the pervasive developmental disorders include childhood disintegrative disorder; Rett's syndrome; pervasive developmental disorder-not otherwise specified (PDD-NOS); Asperger's disorder; and autistic disorder.

Many of the studies reviewed here involve only individuals from the highest functioning end of the autism spectrum (i.e., average range IQ and above) and therefore do not differentiate between autism and Asperger's syndrome. The reason is twofold, the recency of the Asperger's syndrome diagnostic label (APA, 1994) and the ongoing debate regarding the validity of the Asperger's syndrome diagnosis. Although controversial, current diagnostic rules designate early cognitive and language development as the major differentiating criteria between Asperger's syndrome and high-functioning autism. In the case of language development for individuals with Asperger's syndrome, "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)", though the vagueness of this criterion has come under fire. For more general cognitive development, individuals with Asperger's syndrome are differentiated from those with autism in that "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." (APA, 1994, p. 77)

Autism is usually diagnosed during its period of most prototypical presentation, that is, the preschool years (approximately 2.5-5 years). Children are typically diagnosed through parental report of behaviours, both past and present, on a diagnostic checklist (e.g., Lord, Rutter & Le Couteur, 1994) or via observation of current behavioural manifestation (e.g., Lord et al., 2000) by trained and experienced clinicians. However, autism is a lifelong disorder and may be diagnosed at any point during development, given that symptoms date from the first three years of life. The commonly utilised diagnostic checklists are based on criteria for autism published in the DSM-IV. The criteria are organised into three categories of symptoms, conceptually approximating Wing and Gould's (1979) "triad of impairment": 1) impairment in social interactions, 2) impairment in communication, and 3) restricted, repetitive, and stereotyped patterns of behaviour, interests, and activities.

1.1.1 Social Deficits

Regardless of individual functioning level, social impairments are considered the hallmark of this disorder (APA, 1994). In fact, deficiencies in social communication are among the earliest indicators of abnormal development (Baron-Cohen, Allen, & Gillberg, 1992). For example, retrospective reports by parents highlight imitative games, such as peek-a-boo, as noticeably absent in many children with autism. Moreover, joint or shared attention is characteristically impaired and is in fact among the earliest pathognomonic signs of autism (Adrien et al., 1991; Baron-Cohen et al., 1992; Osterling & Dawson, 1994).

One recent view of the early social deficits observed in autism has described an impairment in social orienting or social approach behaviour (Dawson & Lewy, 1989; Mundy, 1995). For example, across three groups of young children, those with Down syndrome, typically developing (TD) children, and children with autism, Dawson and colleagues (Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1995) compared orienting behaviours toward social (e.g., calling of name) and nonsocial (e.g., shaking rattle) stimuli. As expected, children with autism, unlike the other two groups, demonstrated a significant failure to orient towards either stimulus type, but particularly toward social stimuli. Similar findings have been noted from first birthday videotapes of children later diagnosed with autism. Two groups of investigators (Adrien et al., 1991; Osterling & Dawson, 1994) found minute, but significant, differences; children with autism engaged in fewer face-to-face interactions than did TD comparison children and they were less likely to follow pointing gestures or respond to the calling of their names.

This is further corroborated by other social orienting deficits demonstrated later in development.

Social functioning never normalises in individuals with autism, yet its manifestation often changes considerably with age and developmental level (Volkmar et al., 1987). More specifically, as children with autism mature, social abnormalities become even more noticeable and salient when compared to their peers. For example, individuals with autism often prefer isolation to the presence of others and show a deficient understanding of social rules and conventions (e.g., Loveland, Pearson, Tunali-Kotoski, Ortegon, & Gibbs, 2001). However, contrary to stereotypical views, young children with autism are capable of establishing and maintaining secure attachments with caregivers (Capps, Sigman, & Mundy, 1994), and they both enjoy and respond appropriately to tickling and other physical games (Sigman, Mundy, Sherman, & Ungerer, 1986; van Engeland, Bodnar, & Bolhuis, 1985). Similarly misunderstood, children with autism can be quite affectionate toward select individuals, albeit sometimes in an idiosyncratic manner.

Individuals with autism are often described as emotionally flat or unresponsive; however, findings from research paint a different picture. Parents describe their children with autism as displaying more negative emotions, such as fear, anger, and sadness, but fewer positive emotions, such as joy and interest, than do parents of TD children or those of children with moderate learning difficulties (MLD) (Capps, Kasari, Yirmiya, & Sigman, 1993).

Given the one-sided and pedantic style that often characterises the speech of high functioning individuals (see next section), normal friendships with their peers are very uncommon (Bauminger & Kasari, 2000). However, such a communication style may lead to strong interpersonal relationships with teachers, parents, and other adults (Mesibov, 1983).

1.1.2 Communication Deficits

Communicative impairments in autism can range from lack of speech and limited use of gestures and eye contact to problems with the melody and rate of speech (Fine, Bartolucci, Ginsberg, & Szatmari, 1991). Early in development, it has been found that, unlike TD toddlers, young children with autism do not exhibit the usual preference for listening to their own mother's speech (Klin, 1991). Approximately one-third to one-half of individuals with autism do not develop functional speech (Lord & Paul, 1997), but even those individuals with functional linguistic skills demonstrate difficulties with other forms of communication. For example, many verbal individuals are echolalic, meaning they may repeat all or portions of what they hear, whether very recent (i.e., immediate echolalia) or temporally distant (i.e., delayed echolalia) (Prizant, Schuler, Wetherby, & Rydell, 1997). Even for those individuals who are verbal, speech is often odd, with monotonic or robotic-like qualities. It follows then that meaning is not appropriately conveyed via intonation in speech (Baltaxe, 1984; Paul, Augustyn, Klin, & Volkmar, 2005).

Classic early reports of nonverbal communicative behaviour in autism include reference to their utilisation of instrumental gesturing, such as guiding an adult's hand toward a desired object. This stands in stark contrast to their very rare to nonexistent use of gesturing to share an emotion or experience (Attwood, Frith, & Hermelin, 1988). Other forms of nonverbal signalling are also impaired; caregivers frequently report gaze aversion or odd use of gaze (e.g., looking at someone only out of the corner of one's eyes).

Pronoun reversal is a robustly documented developmental difficulty exhibited by children with autism. I-you confusions are frequent and can seriously disrupt communicative efficacy (Lee, Hobson, & Chiat, 1994). Generally, the tendency for echolalia plus difficulties with perspective taking, are thought to underlie this problem.

For those individuals with speech, conversational failure in autism generally results from a failure to grasp basic conventions, such as signalling, turn taking, and providing appropriate context for listeners. Without these conventions, odd and one-sided conversations emerge, often involving seemingly all-absorbing restricted interests.

Individuals with autism prefer concrete to abstract aspects of their world. This carries over to conversational discourse, meaning that they often understand communicative exchanges only in extremely literal ways. Such receptive language limitations contribute to their difficulty with some forms of humour and figurative language (Happé, 1993).

1.1.3 Restricted and Repetitive Behaviours

This final cluster of behavioural symptoms can be divided into two groups: 1) restricted interests and routines and 2) repetitive behaviours and stereotypies, though the distinction may be arbitrary at times, with obvious overlap. The first subgroup of behaviours can be expressed in many ways. For example, the play patterns of children with autism are often restricted and repetitive as demonstrated early in development via deficient symbolic, pretend, and imaginative play. A child with autism may have great difficulty representing one object as another, such as dropping blocks into a pot and stirring them in order to represent food that is cooking. Younger children with autism often demonstrate an unusual interest in non-functional aspects of objects, such as their texture or smell, resulting in idiosyncratic utilisation of objects and toys.

Moreover, flexibility is an area of relative difficulty for these individuals so that tolerating changes to one's routine or environment becomes a significant challenge. A child with autism may become very distressed if his/her daily schedule is altered or if s/he notices that a minute detail has been changed in his/her room, such as changing the placement of a book on a bookshelf.

Higher functioning people with autism may focus on narrow and rather mundane bits of knowledge such as bus schedules, maps, and routes or on idiosyncratic topics such as the space shuttle. Unfortunately, of the triad of impairment this area of behaviours has received the least amount of research interest, partly because these symptoms are not specific to autism. However, what may be most interesting and informative is not the question of specificity, but rather the quality and quantity of these symptoms. For example, obsessive-compulsive behaviours are quite common in individuals with autism, but the nature of these behaviours is very different from those present in obsessive-compulsive disorder (OCD). McDougle and colleagues (1995), utilising a standard measure of obsessive-compulsive symptoms (i.e., the Yale-Brown Obsessive-Compulsive Scale), showed generally elevated levels of repetitive behaviour/compulsions as compared to repetitive thoughts/obsessions within a group of adults with autism, while adults with OCD demonstrated relatively equal numbers. Although these findings are informative and interesting, they are limited by the instrument used; one intended for patients with OCD and created with this population in mind. Unfortunately, the case remains that very little research (but see Baron-Cohen & Wheelwright, 1999) has examined autism specific restricted interests. In an exception to this, Baron-Cohen and Wheelwright designed an instrument with autism in mind, which enabled them to make a distinction between autism related insistence on sameness and restricted interests versus the obsessive-compulsive behaviours commonly presented in OCD.

The second class of behaviours composing the final portion of the triad of impairment includes repetitive behaviours and motor stereotypies. Parental anecdotes of early behaviour frequently include examples of repetitive behaviour such as continually lining up toys or blocks in a row or perseveratively spinning the wheels on a toy car. Stereotypies and repetitive movements and mannerisms may include hand flapping, head bobbing, and tics. These repetitive behaviours are often associated with learning difficulties and poor outcome in ASD. Overall, a poverty of flexibility and fluency in behaviour encapsulates the third aspect of the triad of impairment observed in autism (e.g., Turner, 1999).

It is important to note that the behaviours comprising the triad of impairment in autism interact, often compounding difficulties experienced by these individuals. For example, as mentioned in the previous section, these restricted interests often spill over into social interaction so that a conversation with a peer becomes a pedantic, one-sided speech on very specialised topics described at the most intricate level.

1.1.4 Other Associated Characteristics

Although not part of the current diagnostic definition, other characteristics are commonly associated with this disorder. Approximately three out of every four persons with autism are male (Gillberg, 1995; Wing, 1993), about seven out of ten have learning difficulties (Bryson, Clark, & Smith, 1988), and approximately 20-30% develop seizures at some point in their lives (Volkmar & Nelson, 1990). Some individuals with autism exhibit unusual motor movements such as arm-flapping, facial grimacing, and odd walking styles, as well as self-injurious behaviours, like head banging and finger or hand biting. In addition, they sometimes demonstrate over- or under-arousal associated with sensory stimulation (for example, resistance to being touched or ignoring sensations such as pain).

Another marked characteristic of this disorder is the odd mixture of cognitive strengths and weaknesses. A particular individual may demonstrate limited ability to express or understand speech, while paradoxically demonstrating the ability to navigate fluently a driver's route without looking at a map. In even more extreme and rare cases, "islets of ability" known as savant skills are present (see Chapter 3). For example, Langdon Down (1887) described a patient with numerous cognitive difficulties who nevertheless memorised word for word all of Edward Gibbon's "The Decline and Fall of the Roman Empire".

Perhaps the most intriguing aspect of this disorder is that individuals sharing the diagnostic label termed autism are ultimately very different from one another. Individuals with autism run the gamut with respect to range of cognitive and daily functioning. For example, educational placements may range from special schools, to special education classrooms in regular schools, to inclusion in regular classrooms, and adult outcomes may range from completing a university degree with independence in vocational and daily living settings to requiring lifelong residential care (Howlin, Goode, Hutton, & Rutter, 2004). It is no wonder then that seeking a common underlying cause for such a diversity of symptom expression has proven a significant challenge to the research community.

1.1.5 Epidemiology

Autism was once thought to be a very rare disorder (i.e., 4-5 out of every 10,000 individuals); however, recent evidence has cast serious doubt on these earlier findings. Recent estimates of the prevalence of autism, strictly defined, are approximately 10-12 out of every 10,000 individuals (Fombonne, 1999), but this figure rises considerably when including the entire autism spectrum (Baird et al., 2000; Chakrabarti & Fombonne, 2001). Undoubtedly, there are a number of reasons for the increase in prevalence, not the least of which relate to the broadening of diagnostic criteria (Gernsbacher, Dawson, & Goldsmith, 2005). As Wing and Gould's (1979) notion of an autism spectrum has continued to win favour and gain acceptance among the research and clinical communities, there has been greater recognition of the variety of presentations of social disability. Similarly, Wing's (1981) and Frith's (1991) introduction of Hans Asperger's (1944) work and syndrome to the English-speaking scientific community has undoubtedly had a significant impact upon recent epidemiological surveys. In fact, clarification of autistic symptom expression across all functioning levels, though especially within the lowest and the highest functioning individuals, has served to contribute toward increased prevalence rates (Bryson & Smith, 1998). Because total population studies of the entire cluster of disorders on the autism spectrum are rare, prevalence figures of 20-40 per 10,000 are based primarily on estimates from pooled data (Bryson & Smith, 1998; Fombonne, 1999).

1.2 Aetiology

Despite sustained efforts, the cause of autism remains a mystery. Perhaps, 10 (Rutter, Bailey, Bolton, & LeCouteur, 1994) to 30% (Gillberg & Coleman, 1996) of cases have a known cause. Currently researchers are focussing their efforts on elucidating the likely multiple causes of this unique disorder, concentrating on the interactions between genetics, brain development and function, environmental toxins, and other determinants. A very small proportion of individuals with autism have documented prenatal conditions, such as genetic abnormalities (e.g., tuberous sclerosis or fragile X), infectious diseases (e.g., rubella), and/or structural abnormalities (e.g., hydrocephalus) that may have contributed to the disorder (Fombonne, Du Mazaubrun, Cans, & Grandjean, 1997). Perinatal factors have thus far received very little support as causative agents in the development of autism (Nelson, 1991). However, postnatal factors, which may significantly increase the chances for developing autism, include untreated phenylketonuria, infantile spasms, and herpes simplex encephalitis (Gillberg, 1986, 1991).

1.2.1 Genetics

The importance of genetic factors to the aetiology of autism is almost unquestionable. Concordance rates for subclinical expression of the autism phenotype in monozygotic twins are high (~90%), especially when contrasted with the rate (5-10%) among same-sex dizygotic twins (Bailey et al., 1995). Such a discrepancy indicates a significant genetic loading in the transmission of autistic traits. The seminal efforts of Folstein and Rutter (1977) involving 21 same-sex twin pairs, 11 monozygotic and 10 dizygotic, in which at least one twin had autism, first indicated the importance of genetic factors in autism. Since then, exponential growth surrounding the potential genetic mechanisms at work in autism has occurred. In fact, based on current evidence, autism has the highest genetic liability of any psychiatric condition; however, the patterns of inheritance remain unclear (Rutter, 2000).

When considering the sex ratio of three males to every female in autism, males have a significantly elevated risk of developing autism. Unfortunately, this male overrepresentation, repeatedly documented since Kanner's original description in 1943, has yet to be fully explained within the extant literature (though see the current work of Baron-Cohen, 2002; Baron-Cohen & Belmonte, 2005). Given the presumed importance of genetic factors in the aetiology of ASD, it is not surprising to note that one common approach to investigating this issue has focussed on the contributions of potential abnormalities of the X chromosome. Males rely on one X chromosome and one Y chromosome, while females rely on two X chromosomes for genetic information and expression. For females, having two X chromosomes often masks or dilutes effects of a damaged X chromosome. Indeed, this rationale led Skuse and others to investigate the overlap of autism and/or autistic traits and Turner's syndrome, a genetic disorder in which females have one X chromosome completely or partially missing. Investigations by this research group demonstrated at least one key overlapping characteristic; females with Turner's syndrome, similar to individuals with ASD, often avoid eye contact

(Lawrence et al., 2003). Moreover, one controversial supposition, based on findings of superior social cognitive skills amongst paternally derived versus maternally derived cases of Turner' syndrome, is that a key genetic locus for social cognition is paternally derived, placing males, whose X chromosome is maternally derived, at greater risk for disorders of social cognition, like autism (Skuse et al., 1997).

The few molecular genetic examinations undertaken have not revealed causative relationships between autism and the X chromosome. However, for well over a decade, fragile X syndrome was thought to be vastly over-represented in individuals with autism (e.g., Gillberg & Wahlström, 1985). Recent investigations (e.g., Bailey et al., 1993; Dykens & Volkmar, 1997; Feinstein & Reiss, 1998) have since clarified this relationship, lessening its magnitude and hence, its explanatory power. It now remains unclear as to what extent the fragile X syndrome elucidates the aetiology of autism. However, overlapping symptom expression (regardless of IQ level), such as stereotypies, perseverative behaviour, deviant aspects of language, and difficulty modulating sensory information and affect (Rutter, Bailey, Simonoff, & Pickles, 1997) are powerful indications of possibly shared aetiological mechanisms.

What is becoming clearer is the importance of investigating what has been termed the broader phenotype of autism. The broader phenotype has been conceptualised as subthreshold/subclinical expression of autistic symptomatology, and other related aspects of the clinical picture in autism (e.g., cognitive style and deficits) in family members of those affected with the syndrome. The broader phenotype represents the genetic liability for some of the same traits as present in autism, but in a qualitatively milder expression. For example, initial investigations in this area indicated abnormalities within the domains of social language use (Landa, Wzorek, Piven, Folstein, & Isaacs, 1991) and other social skills (Piven et al., 1991) as well as atypical personality features (Piven et al., 1994) as components of the broader phenotype in family members. More recently, these studies have been extended to attempt to delineate the boundaries of the broader phenotype by examining other, non-diagnostic characteristics of autism. For example, recent studies have documented impaired theory of mind and executive dysfunction (robust findings in autism and briefly reviewed later in this chapter) in both parents (Baron-Cohen & Hammer, 1997; Hughes, Leboyer, & Bouvard, 1997; Piven & Palmer, 1997) and siblings (Dorris, Espie, Knott, & Salt, 2004; Hughes, Plumet, & Leboyer, 1999) of individuals with autism. Similarly, as compared to parents of children with dyslexia and those of TD children, fathers of children with autism have shown disproportionate interest in nonsocial activities and a detail-focussed information processing style that can give advantages for certain tasks such as the Block Design task and the Embedded Figures Test (Briskman, Happé, & Frith, 2001; Happé, Briskman, & Frith, 2001).

Of particular relevance to the present thesis are two recent genetic studies subgrouping individuals with autism based on the presence of splinter and savant skills. Nurmi and colleagues (2003) identified 21 families, among 94 multiplex families, as "savant skills positive" and 73 families as "savant skills negative". The "savant skills positive" families demonstrated significantly elevated linkage to 15q11-q13 compared to "savant skills negative" families. Interestingly, Prader-Willi syndrome is due to a deletion on the same region of chromosome 15 (i.e., 15q11-13) and shares some cognitive features (including good jigsaw-type puzzle skills, for example) with autism. This study points to the potential importance of splinter and savant skills in the aetiology of autism. However, in an attempted replication with 91 multiplex families, Ma et al. (2005) failed to confirm Nurmi et al.'s findings of linkage to chromosome 15 through subgrouping based on the Autism Diagnostic Interview's (ADI) savant skills questions. Nevertheless, these equivocal findings beg for further investigation into the link between genetics and splinter or savant skills, perhaps incorporating more detailed assessment of these skills beyond that provided by the ADI.

1.2.2 Environmental Contributors

Investigations into potential environmental contributors to autism aetiology are truly in their infancy stage. Undoubtedly, one reason for the dearth of studies in this area involves the early history of autism. Strongly influenced by psychodynamic developmental theory, early investigators pointed to "refrigerator mothers" (i.e., cold and distant in their interactions) as the cause of autism. Even after psychodynamic developmental explanations for many psychological disorders lost favour, it took more than a decade before this engrained notion was rooted out of the clinical community. It is therefore understandable that many investigators, until recently, have used caution when invoking environmental factors as significant to the aetiology of autism.

Just within the past decade, these types of investigations have begun on a small scale. For example, one line of research has examined co-morbid cases of foetal alcohol syndrome and autism (Harris, MacKay, & Osborn, 1995) and investigated case histories of adults with autism, a significant portion of whom upon retrospective review of records were found to have histories of prenatal alcohol exposure (van Karnebeek et al., 2002). These studies converge in suggesting that early exposure to alcohol and other drugs may increase the chances of developing autism and/or autistic symptomatology. Similarly, based on clinical case studies and animal models, another area of investigation has implicated prenatal valproic acid exposure as increasing the risk of developing autism (Ingram, Peckham, Tisdale, & Rodier, 2000; Williams et al., 2001). Exposure to valproic acid in prenatal rats during neural tube development results in cerebellar damage similar to that documented, via neuroimaging studies, in autism (e.g., Courchesne, Yeung-Courchesne, Press, Hesselink, & Jernigan, 1988). However, cerebellar damage is not specific to autism and its functional repercussions can be quite varied (e.g., Ivry & Justus, 2001). Thus, mapping these environmental contributors not only to brain abnormalities found in autism, but also to the accompanying behavioural repertoire will prove to be no small feat.

Studies of other teratogenic agents, such as thalidomide, indicate that a subset of cases with autism may be due to maldevelopment of the brain stem (Rodier, 2002). Stromland, Nordin, Miller, Akerstrom, and Gillberg (1994) noted that thalidomide exposure to pregnant women resulted in a significant number of neurodevelopmental disorders in their offspring. Upon closer examination, it became clear that thalidomide exposure during the first trimester, particularly between the 20th and 24th days of gestation, lead to a significant risk of developing autism (five out of 15 cases). This finding lead to the hypothesis (that continues to be investigated) that autism may trace its roots to early embryopathy. Teratology has only recently turned its attention to the field of autism. As more potential environmental triggers are examined, a better understanding of not only environmental factors in autism, but also gene-environment interplay, will be possible.

Perhaps the most controversial and undoubtedly the most hotly debated postulation regarding the environmental origin of autism stems from its possible association with the Measles-Mumps-Rubella (MMR) triple vaccine. The primary evidence for this association involved two coincidental factors: 1) the corresponding timing of the MMR vaccine and the onset of symptoms in autism and 2) the recent rise in cases of diagnosed autism roughly corresponding to the relatively recent adoption of the triple vaccine over three separate vaccines for measles, mumps, and rubella. Since vaccination is mandatory in many Western countries and the triple vaccine is manufactured almost to the exclusion of the single doses, a suggestion of detrimental effects had, and continues to have widespread ramifications in terms of public health.

Although the debates continue, a series of sound epidemiological studies conducted to date have not provided evidence that MMR is a causative agent in the development of autism (e.g., Fombonne & Chakrabarti, 2001; Fombonne, Zakarian, Bennett, Meng, & McLean-Heywood, 2006; Honda, Shimizu, & Rutter, 2005; Taylor et al., 1999). Ethyl mercury, a component of the preservative used in the MMR jab and other immunizations (prior to 2001 in the US), was implicated particularly. Though evidence thus far refutes the aetiological significance of immunizations containing mercury-based preservatives, mercury has also been implicated recently as an environmental toxin in air pollution that may contribute to increased rates of ASD (Windham, Zhang, Gunier, Croen, & Grether, 2006).

Utilising a complementary approach to teratology, Rutter and colleagues (1999) compared six-year-old British children adopted from Romania and those adopted within the UK, and found that a significant minority (12%) of the Romanian born adoptees exhibited a "quasi-autistic pattern" of behaviour. These Romanian adoptees, unlike their British peers, experienced severe privation, which resulted in poorly developed attachment relationships and cognitive impairments. The study of adoptees that had experienced these living conditions early on provided a rare (non-teratogen-related) environmental model of autistic behaviour in humans.

In summary, despite recent findings from studies of environmental toxins, early privation, and so forth, much of the research in this area is based on very small sample sizes and/or animal models whose applicability to autism is as yet unknown. As interest in this research pursuit continues to gain momentum, more rigorous research methods will be applied and provide more definitive conclusions regarding the environmental contributors to autism.

1.2.3 Neuropathology and Neuroimaging

As yet, at the neuroanatomical level, there is no consensus regarding localisation of damage or dysfunction; thus, there is no globally accepted pathophysiologic theory of autism. Autopsy and postmortem studies have revealed what can be considered only preliminary neuropathological findings because of their reliance on a very small number of brains (for review, see Palmen, van Engeland, Hof, & Schmitz, 2004). Findings have indicated abnormalities restricted to the limbic and cerebellar regions. At the microscopic level, a lowered number of Purkinje cells and granular cells has been noted in the cerebellum (Bauman, 1991; Ritvo et al., 1986). Paradoxically, there was a higher density of cells in some cerebellar nuclei and limbic structures, including the hippocampus and amygdala (Bailey et al., 1998; Bauman & Kemper, 1985). Furthermore, converging evidence from clinical (e.g., Lainhart et al., 1997), structural neuroimaging (e.g., Piven, Arndt, Bailey, & Andreasen, 1996), and neuropathological investigations indicates that, as a group, the brains of these individuals tend to be significantly larger than average (macrocephaly or megalencephaly). In fact, when group data are more closely scrutinised, a specific subgroup emerges which seems to be responsible for the larger group effects (Fombonne, Roge, Claverie, Courty, & Fremolle, 1999). Recent studies indicate that macrocephaly may be restricted to the early years in autism (Courchesne, Carper, & Akshoomoff, 2003). In any case, this potential subtype of autism has begun to garner greater attention, especially as it relates to genetic aetiology (e.g., Butler et al., 2005).

Overall though, structural neuroimaging has often resulted in inconclusive and/or conflicting results, such as smaller hippocampal formations in one study (Saitoh, Karns, & Courchesne, 2001), but not in another (Piven, Bailey, Ranson, & Arndt, 1998). In addition to brain enlargement, two of the most consistent findings at the group or subgroup level are abnormalities of the cerebellum (e.g., Courchesne et al., 1988; Hardan, Minshew, Harenski, & Keshavan, 2001) and reduced size of the corpus callosum (e.g., Hardan, Minshew, & Keshavan, 2000; Manes et al., 1999; Waiter et al., 2005). Even though these represent the most consistent findings across various laboratories, this does not mean that there have not been conflicting results from other laboratories. Quite the contrary, as one lab implicates one brain region, another documents null results for that region. Obviously, differences in methodology between studies (e.g., inclusion versus exclusion of individuals diagnosed with both autism and MLD, use of appropriate control groups to account for associated characteristics like MLD, age range of participants, and acuity of equipment) make comparisons between them very difficult.

From their inception, functional neuroimaging studies of autism have been riddled with methodological constraints. Early studies were characterised by small sample sizes (usually less than 20 individuals with autism) and older diagnostic definitions as well as technological constraints. More recent investigations have moved beyond examination of resting state versus active state glucose metabolism and toward more dynamic approaches, such as linking cognitive findings with neural activity. For example, Happé et al. (1996) utilised PET to compare brain activation of typical adults and adults with Asperger's syndrome while they completed a story task assessing social insight versus a non-social, physical story (Happé, 1994a). Most notably and discrepant from typical adults, adults with Asperger's syndrome did not utilise area 8/9 of the paracingulate cortex when completing comprehension questions for mentalising stories. In a similar vein, a functional imaging study of featural versus global information processing style (i.e., central coherence) conducted by Ring and colleagues (1999) utilised fMRI to examine cerebral correlates of performance on the Embedded Figures Test, a task on which individuals with autism perform as well or better than typical individuals (Shah & Frith, 1983), as compared to visual fixation, a relatively non-specific control task. Results indicated different patterns of activation between controls and individuals with autism, with the former group reliant on working memory systems and the clinical group utilising the visual system for featural processing.

In autism, unlike TD children, there is no face specific activation of the fusiform face area (Boucher & Lewis, 1992; Hauck, Fein, Maltby, Waterhouse, & Feinstein, 1998; Hobson, Ouston, & Lee, 1988). Recent neuroimaging research has found that for high functioning adults with autism, faces are processed in an area of the brain that is typically associated with general object perception (Schultz et al., 2000). It follows then that faces do not seem to have special status in the brain of individuals with autism, rather they are viewed just as any other objects in the environment; though a simple lack of practice in processing face stimuli could also be argued to account for these findings. Indeed, it seems as if (directed) focussing on the eye region of the face results in typical fusiform activation in autism (Hadjikhani et al., 2004).

These studies help to extend behavioural findings (see the major psychological theories section below) by isolating the differences and noting the commonalities in neural mechanisms involved in completing these tasks. Since autism is a brain-based disorder, a long-term goal is to utilise these sorts of findings to inform novel and effective treatments.

1.3 Treatment

As yet, there is no cure for autism; however, treatment approaches abound for caregivers of children with autism. Most interventions focus on the childhood period (i.e., preschool to school age) to the relative exclusion of adulthood. Even long-standing treatment and educational programs lack validation data, primarily due to the need for well-controlled studies, which include elements difficult to enact in clinical practice, such as randomisation of groups.

Medical/biological interventions have included drug and vitamin therapies.

Individuals with autism are idiosyncratic responders to drug therapies and biological treatments. Indeed, drug treatment is symptom-based (targeting anxiety, aggression, hyperactivity, etc.), not a cure. The 20-30% of individuals with autism and epilepsy are helped by anticonvulsant medication. Amphetamines, lithium, anti-depressants, and anti-anxiety medications have all been utilised with varying degrees of success depending upon the individual. Megavitamins and secretin have also been administered to children with autism based on claims of small but notable symptomatic improvement (e.g., Pfeiffer, Norton, Nelson, & Shott, 1995). When examined with scientific scrutiny, secretin treatment has not proven effective in alleviating autistic symptomatology at the group level (e.g., Sandler et al., 1999; for review, see Esch & Carr, 2004); however, particular individuals may respond positively.

Behavioural/psychoeducational interventions (see Howlin, 1998 for review) have emphasised the positive reinforcement of appropriate behaviour and the elimination of inappropriate behaviour along with the accommodation of the classroom and other environments to maximise potential; all completed within the least restrictive environment to each individual child. Indeed, the behavioural approach has been utilised frequently in school settings to help develop academic and self-help skills in individuals with autism.

Behavioural interventions are effective in improving the daily functioning of people with autism. Based on learning theory, these techniques continue to influence programs for people with autism and other developmental disabilities. Three major behavioural approaches have been applied to treatment: operant, cognitive, and social learning. Operant techniques utilise the straightforward application of the principles of learning theory; clear and direct reward and punishment. Desirable behaviours are paired with positive events, while undesirable behaviours are paired with negative consequences (e.g., loss of privileges). This approach is generally effective and remains common practice, but some professionals opt for more positive techniques in lieu of this approach or to bolster these techniques.

Building on the success of behavioural interventions, structured teaching was developed as a complementary way of assisting children with autism to maximise their abilities and to minimise their inappropriate behaviours (Schopler, Mesibov, & Hearsey, 1995). This approach first assesses how well a person with autism can understand the environment and expectations for behaviour. Positive reinforcers and undesirable consequences are then used to clarify this understanding. Other tenets central to the structured teaching technique include organising the physical environment, using schedules, assessing individual strengths and weaknesses, and establishing positive routines. Summarily, it is a cognitive-behavioural approach that seeks to individualise educational intervention, to make the environment more predictable and manageable, and to utilise behavioural techniques to shape behaviour.

Most appropriate for verbal individuals, social learning approaches emphasise social skills training. Deficient social skills are targeted and appropriate behaviours practiced in a naturalistic setting, often in the context of a social skills training group. Specific techniques for teaching include modelling, role-playing, and rehearsal (see, for example, Mesibov, 1984; Pierce & Schreibman, 1995).

Because of the early onset of autism, early intervention has been an area of intense focus, attempting to generate meaningful long-term changes and improvement in outcome. Indeed, there have been numerous reports of improvement in linguistic, cognitive, and adaptive skills amongst children with autism after intensive early intervention (Rogers, 1998). Unfortunately, logistical and methodological limitations have prevented strong empirical validation of the long-term effectiveness of early intervention (Howlin, 2003).

With the increased awareness of autism as a lifelong developmental disability, vocational training has received recently greater attention. When given adequate support and training, many individuals with autism obtain competitive jobs, especially those that can be matched to a particular individual's strengths and/or interest area(s). Such recent social gains have increased the opportunities for individuals with autism to lead fulfilling and productive lives.

1.4 Major Psychological Theories

Theories that attempt to explain the greatly variable expression of autism aetiology are plentiful, but three theories (two briefly reviewed here and one reviewed more comprehensively in Chapter 2) currently have the largest accompanying bodies of literature (both supporting and refuting their predictions) and are most relevant to the topic of savant skills. The current tone of the literature tends to favour a multiple-deficits account, since a single, unitary deficit can not adequately explain all features of the disorder.

1.4.1 Theory of Mind

The ability to think about thoughts and to attribute mental states, such as desires, beliefs, and intentions, to oneself and to others is described as "theory of mind". It has been suggested that deficits in theory of mind, the ability to "mind-read", represent the clearest characterisation of social difficulties experienced by individuals with autism (Baron-Cohen, Leslie, & Frith, 1985). The original study demonstrating this deficit in individuals with autism involved a first-order false belief task (Baron-Cohen et al., 1985). Puppets were used to demonstrate a simple scenario involving Sally and Ann. The following is a brief description of this sequencing task: Sally has a basket and Ann has a box. Sally places her marble into her basket and goes out for a walk. While she is gone, Ann takes the marble from the basket and puts it into her box. Sally then returns, wanting to play with her marble. The question is then posed to the participant, "Where will Sally look for her marble?" Most of the participants with autism said that Sally would look in the box, while the controls predominantly said she would look in the basket. The child with autism is asked to put him or herself "in someone else's shoes" and represent his/her mental state. A number of researchers have subsequently validated the finding that children with autism have much greater difficulty with theory of mind tasks than same (mental or chronological) age TD children and children with MLD (e.g., Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997; Happé, 1994a; Leekam & Prior, 1994).

A great deal of research investigating theory of mind in both typical and other atypical populations has been conducted since the seminal efforts of Baron-Cohen and his colleagues. Evidence thus far implicates emergence of basic theory of mind skills, such as understanding that others may have a false belief, around four years of age (e.g., Wimmer & Perner, 1983), though this depends on whether you are testing these classic theory of mind domains or precursor skills, such as pretend play. Indeed, a number of methods has been developed in order to investigate theory of mind across the lifespan including experimental tasks such as false belief, representational change, appearance-reality, and deception as well as more naturalistic measures such as the "Awkward Moments" test, informant ratings based on items from the Vineland Adaptive Behaviour Scales, the "Strange Stories" test, the "Eyes Test", and the faux pas test (see Baron-Cohen, 2000 for review).

The theory of mind account does an exceptionally good job of describing the social deficits observed in autism (see Frith & Happé, 1998). It explains, for example, why individuals with ASD may be socially interested yet socially disconnected and why they have difficulty with lying and keeping secrets. Nevertheless, one significant shortfall of the theory of mind account is its inability to account for the full range of symptom expression in ASD. Most salient is its inability to explain the relative strengths present in the cognitive profile of autism and the restricted interests and/or repetitive behaviours required for diagnosis. Another potential shortcoming of the theory of mind theory is that a small minority of individuals with an ASD passes the tests. Specifically, people with Asperger's syndrome, those on the autism spectrum with the highest verbal ability, are more likely to pass false belief tasks (Bowler, 1992). This finding, in conjunction with the demonstrated relationship between verbal ability and theory of mind task performance (e.g., Garfield, Peterson, & Perry, 2001; Happé, 1995), has led some researchers to postulate that theory of mind tasks, such as false belief can be solved via verbal instead of social cognitive routes (Happé, 1995). One alternative idea indicates that theory of mind deficits represent a delay in acquiring these abilities since intact/age appropriate theory of mind has not been documented in very young children with autism.

1.4.2 Executive Function

A sometimes competing but possibly complementary approach to explaining the deficits seen in autism is the executive function account. The umbrella term executive function refers to those flexible goal-directed behaviours thought to be mediated by the frontal cortex. An overall definition is the ability to maintain a problem-solving set appropriate to the situation, in order to attain a future goal (Duncan, 1986; Welsh, Pennington, & Groisser, 1991). Planning, flexibility of thought and action, organisation of materials and cognitive processes, impulse control, and holding a mental representation "on-line" have all at one time or another been subsumed within this category. One of the earliest attempts to formulate a neuropsychological characterisation of autism (Damasio & Maurer, 1978) utilised the frontal metaphor to account for some aspects of symptom presentation, such as perseverative behaviour and difficulty with higher-level linguistic and cognitive skills. Subsequent to this initial comparison of the behaviour exhibited by adults with frontal lesions and by individuals with autism, a growing body of literature has sought to validate empirically executive dysfunction in autism.

Judy Rumsey and her colleagues carried out the first seminal investigations examining executive functioning in autism. Results from a series of studies utilising classic measures of frontal lobe functioning, such as the Wisconsin Card Sorting Test, consistently demonstrated executive dysfunction amongst high functioning adults with autism (Rumsey, 1985; Rumsey & Hamburger, 1988, 1990). Investigators then extended these studies to include children and adolescents on the autism spectrum, finding much the same results as the adult studies (Hughes & Russell, 1993; Ozonoff, Pennington, & Rogers, 1991; Prior & Hoffman, 1990). However, executive functioning includes a number of behaviours and subdomains, so the onus falls on specifying the particular subdomain(s) that seem to be consistently and uniquely impaired in autism. Based on purported executive function tasks, the findings thus far implicate perseveration as the most clearly and consistently documented deficit area (Liss et al., 2001; Sergeant, Geurts, & Oosterlaan, 2002).

However, it is difficult to arrive at definitive answers regarding the applicability of executive function accounts to ASD because of at least two problems that face this line of inquiry. The first is the issue of specificity; executive functioning difficulties are common amongst a variety of developmental disorders, though the executive functioning profiles may vary. The second limitation is the relatively limited data available on early executive functioning in ASD. Studies by Griffith, Pennington, Wehner, and Rogers (1999) suggest that executive function difficulties are not autism specific at ages three to four years, even though they distinguish older children with autism from children with MLD. Therefore, based on this evidence, it is unlikely that executive difficulties represent a primary impairment in ASD.

As has become clear from the theory of mind and executive function accounts, it is highly unlikely that a single primary deficit account will ever truly capture the diversity and variability of behavioural expression observed in ASD. After all, it has been argued for some time that autism may be a disorder of multiple primary deficits (Goodman, 1989). Moreover, these two areas as well as the weak central coherence (WCC) account reviewed in the next chapter, do not necessarily oppose one another. A more thorough integration of these theoretical accounts is needed, because each may contribute a piece of the puzzle to understanding autism. Indeed, what has been highlighted by briefly reviewing the two most prominent deficit-based accounts of autism is the lack of explanatory power for the cognitive and behavioural strengths of autism, which are frequently mentioned in both the anecdotal and research literature. The third of the three major psychological theories of autism, WCC, attempts to account for these cognitive strengths and is reviewed in detail in the next chapter.

1.5 Summary

In this chapter it is evident that autism is a highly heritable neurodevelopmental disorder, yet its aetiological origin remains a mystery. Individuals with autism present with an unusual and distinctive cognitive profile which includes both assets and deficits. Given that assets can reveal as much about a disorder as deficits, although deficit-based models have dominated the extant literature, this thesis aims to examine more closely potential cognitive assets and how they may contribute to splinter and savant skills that occur more frequently in autism than in other developmental disorders.

Chapter 2: Beyond Deficits: Cognitive Style in Autism Spectrum Disorders

Deficit-based models have long been the default approach to examining cognitive functioning within clinical populations. ASD are no exception, with many of the current neuropsychological conceptualisations grounded in deficit-based accounts (e.g., executive function and theory of mind). However, the significance of identified deficits can only be assessed against a background of task success (Happé, 1999), and deficit-based accounts fail to explain aspects of cognitive performance that would be considered intact, or even enhanced (e.g., savant skills). Savant skills, perhaps even relative cognitive strengths (i.e., "islets of ability"), such as good rote memory and a good "eye for detail" may on the surface appear to be superfluous to cognitive accounts of autism, but when considering the disproportionate rate of occurrence in ASD as compared to idiopathic learning difficulties (10% v. <1%), some level of explanation is required.

Briefly reviewed at the end of Chapter 1 were two psychological theories (theory of mind and executive function) that attempt to account for signs and symptoms of ASD. How these theories apply to better understanding the overrepresentation of savant skills in ASD is mostly indirect, rather than providing straightforward predictions. So, for example, based on the theory of mind account, individuals with ASD are not concerned with what others think, allowing them to follow their own line of reasoning and interests, which may be key to creative expression. On the other hand, the executive function theory holds that individuals with ASD have difficulty shifting attention, which may account for their becoming all-absorbed in their interest areas (including art and music), some of which many TD individuals would find mundane (e.g., calendars). By contrast, the WCC account was specifically inspired by the need to explain islets of ability. The following chapter aims to review the literature on WCC in autism, particularly as it relates to savant skills, and briefly introduce alternative accounts for the pattern of cognitive strengths observed in autism.

2.1 The Weak Central Coherence Account

In her seminal discussion of the characteristic cognitive features of autism, Uta Frith (1989) described the tendency of individuals with autism to favour local over global processing (a reverse of the typical trend) as a "weak drive for central coherence". Frith conceptualised central coherence in typical development as a driving force to bring together vast amounts of information, implying cognitive efficiency reliant on the use of context and meaning to aid information processing. In essence, strong central coherence is "not seeing the trees for the forest". Initially, the WCC theory was meant to be all-encompassing, so that it accounted for both social and non-social deficits in autism; however, after further empirical scrutiny (e.g., Happé, 1997; Happé & Frith, 2006; Teunisse, Cools, van Spaendonck, Aerts, & Berger, 2001), the latest delineation of WCC theory seems better equipped to account only for non-social features of autism and thus to serve as a complementary account to social theories, such as the theory of mind theory of ASD. The scope of the following review is limited to examination of WCC in ASD, and begins with a review of studies of WCC divided by convenience into perceptual, visuospatial, and verbal-semantic coherence.

2.1.1 Perceptual Coherence

A number of studies have extended the relevance of WCC to low level forms of visual and auditory processing. Jarrold and Russell (1997) presented canonically arranged and distributed (amongst distracter shapes) black dots to assess counting abilities in children with autism as compared to those with MLD and those with typical development, all matched group-wise on verbal mental age. For each group, difference scores were calculated between reaction times (RT) in the canonical and distributed conditions. As predicted by WCC theory, the difference scores were significantly smaller for the autism group than the TD control group, implying that a canonical, global arrangement of dots conveyed a significant advantage for the latter, not the former, group. Similarly, Brosnan, Scott, Fox, and Pye (2004) found that children with MLD more often utilised the gestalt grouping principles of proximity, similarity, and closure than did children with autism. In fact, children with autism were grouping at a level that was not significantly greater than chance, suggesting difficulty grasping relationships between component parts.

Happé (1996) compared susceptibility to visual illusions between individuals with autism versus those with MLD or typical development. Participants were asked questions about the physical properties of the stimuli, such as comparing the length of lines and size of circles. These judgements were made both within an illusory context and within a control condition consisting of the same components, but without the illusory effect. As predicted by WCC theory and in contrast to TD participants and participants with MLD, children with autism succumbed to the illusions significantly less often and did not benefit as much from segmentation of the stimuli in a 3-D condition. Although these findings were intriguing, later attempts failed to replicate and extend this work (see the "Negative Findings" section of this chapter).

Navon hierarchical figures, in which large characters are composed of smaller ones (e.g., large "S" made up of small "T"s), have been utilised in a number of studies assessing visual global and local processing in autism; however, results are mixed with some negative findings (see the "Negative Findings" section of this chapter) and some positive findings. Rinehart, Bradshaw, Moss, Brereton, and Tonge (2000) utilised a numeric version of the Navon hierarchical figures task (1977) to assess the precedence of local and global information for individuals with high functioning autism or Asperger's syndrome. Both clinical and control groups exhibited global advantage (i.e., responding faster to global than local stimuli) and global interference (i.e., processing information globally to the detriment of local details) effects; however, local interference effects were also noted in this and a later study (Behrmann et al., 2006) using alphabetic stimuli, implying that unlike the typical case, global stimuli have no special status in the information processing of individuals with ASD. In a divided attention version of the Navon-type task a participant is not presented with information as to what level the stimuli would appear, while in a selective attention version, a participant is instructed to attend at the local or global level. Plaisted, Swettenham, and Rees (1999) found that when there were no instructions (the divided attention task), children with autism made more errors at the global level, while TD children made more errors at the local level. However, when instructions were provided (the selective attention task), both groups of children were quicker to respond to the global target. These findings indicate that individuals with ASD favour responding at the local level when left to their own volition, but demonstrate a typical global response bias in a directed attention task.

Another domain of lower level processing in which WCC has been demonstrated is face processing. When global configuration is altered, in such a way that participants are asked to recognise inverted faces, performance by people with autism is less detrimentally affected than that of typical individuals, interpreted as reflecting detail-oriented processing (e.g., Langdell, 1978; Tantam, Monaghan, Nicholson, & Stirling, 1989). People with autism often display deficient performance when asked to process the face as a whole (e.g., Gepner, de Gelder, & de Schonen, 1996; Hobson et al., 1988). However, when asked to examine details of a face, for example, through lip reading, people with autism demonstrate comparable performance levels to control participants matched on mental age (e.g., de Gelder, Vroomen, & van der Heide, 1991). Even though lip-reading or visual speech was found to be intact in autism, it had little influence on auditory perception (i.e., reduced McGurk effect), due either to failure to integrate this information or problems in divided attention. Therefore, the tendency to blend speech sounds perceived auditorily and visually, was less marked for children with autism.

Ropar and Mitchell (2002), taking a different approach, examined the perception of shape constancy, based on actual versus viewed shape, in children and adolescents with autism, MLD, or typical development, along with a group of TD adults. Top-down processing was found to be less influential in the autism group in that prior knowledge of the circle's actual as opposed to viewed shape imposed less influence on the perception of the shape.

Also of potential relevance, Gepner, Mestre, Masson, and de Schonen (1995) demonstrated that five children with autism were less susceptible to visually induced motion than age-matched TD children. In a more recent paper, Milne et al. (2002) examined differences in coherent motion processing between a group of children and adolescents with autism and a nonverbal ability and chronological age matched TD control group. Results revealed that people with autism demonstrated higher motion coherence thresholds than matched controls, that is, they had greater difficulty detecting coherent motion, corroborating an earlier study by Spencer et al. (2000) and a later study by Pellicano, Gibson, Maybery, Durkin, and Badcock (2005). Indeed, these results argue for impaired global visual processing in autism, specifically in the magnocellular pathway, which in turn results in an over reliance upon local processing and its relevant neural substrate, the parvocellular pathway. It should be noted; however, that these deficits are not specific to autism; individuals with dyslexia, for example, have similar difficulties (Wilmer, Richardson, Chen, & Stein, 2004). Nevertheless, the documentation of deficits at this low level further calls into question the assumption that perception in autism is indeed typical.

2.1.2 Visuospatial Coherence

A characteristically spiky profile of intelligence subtest scores is well documented in the ASD literature, typically with elevated performance on Block Design in the Wechsler Scales (Happé, 1994b; Lincoln, Allen, & Kilman, 1995; Rumsey, 1992). This visuospatial task represents a prototypical measure of central coherence; approaching the block design task at a detailed level (constituent parts instead of the gestalt or "big picture") may result in superior performance. Indeed, given the affinity for approaching the task at a detailed level, individuals with ASD avoid the difficulty that unimpaired persons experience when completing this type of task, that is, trouble with inhibiting the perception of the gestalt so that the percept can be "broken down" into its constituent parts. As a result, they are little aided by presegmentation of the designs to be copied, unlike comparison groups matched for age or ability (Shah & Frith, 1993).

Similarly, when given the Embedded Figures Test (EFT) (Witkin, Oltman, Raskin, & Karp, 1971; see Figure 2-1 for an item example), individuals with ASD perform comparably or superior to matched controls (Shah & Frith, 1983). The EFT requires one to find as quickly as possible a simple object or figure (e.g., a triangle), which is hidden within a picture of a larger, more complex object (e.g., a crane). Scoring is based on number correct and time needed to locate the hidden figure. Shah and Frith (1983) interpreted their findings in the following way: for TD individuals, the larger, more complex figure was more compelling and thus more difficult to inhibit in order to find the embedded shape. In individuals with ASD, the part is salient and there is little distraction from the gestalt. Jolliffe and Baron-Cohen (1997) replicated these findings, supporting the original contention that people with autism, and also those with Asperger's syndrome, are faster than TD individuals on the EFT.

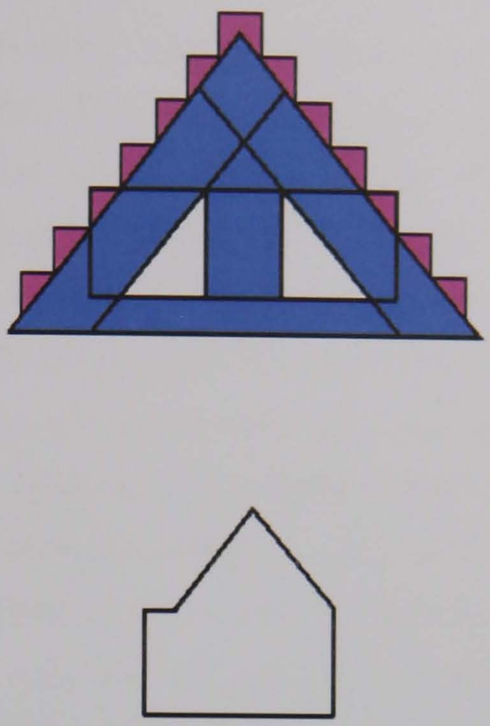


Figure 2–1. Example of an Item from the Standard Embedded Figures Test.

Jolliffe and Baron-Cohen (2001a), in later work, tested the ability of adults with high functioning autism or Asperger's syndrome to integrate pieces of a line drawing into a coherent whole or to note similarities between line drawings. Individuals with ASD were proficient in noticing similarities, but deficient in their ability to integrate pieces into a whole. Furthermore, in a second experiment, these same participants were shown scenes, each containing an object inconsistent with the overall context. Participants were then asked to describe the scene, label the type of scene and its inappropriate content, and locate in the scene a different, named, and contextually incongruent object as quickly as they could. Deficits were noted in their ability, not only to locate the incongruent named object, but also to identify the scene. In another study, these researchers (Jolliffe & Baron-Cohen, 2001b) utilised a modified version of the Hooper Visual Organisation Test (Hooper, 1958) to assess ability to integrate visuospatial information in adults with Asperger's syndrome. As predicted by WCC theory, results revealed good performance when participants were asked to recognise objects from identifying details or fragments and poor performance when recognition required integration of fragments into a whole.

Studies of drawing style and ability in ASD have also suggested detail focus.

Through the use of a novel graphomotor task based on the Rey-Osterrieth Complex Figure (ROCF: Osterrieth, 1944), Jolliffe and Baron-Cohen (1997) sought to document whether individuals with ASD exhibit preferential local processing. Although significant differences were not documented between the clinical and control groups, most likely due to ceiling effects on the ROCF-like task, trends in the data suggested preferential local strategies in the ASD group when drawing the figure from memory. Prior and Hoffman (1990) administered the original ROCF as a purported measure of frontal lobe functioning to 12 children with high functioning autism. Since there was no scoring system for organisation, the authors relied on qualitative analysis when describing approach to drawing the figure. They noted that in the copy condition, children with autism seemed to do as well quantitatively as the chronologically age-matched control group, but that the approach was generally "disorganised," often starting with a detail and proceeding to draw the rest of the figure in a piecemeal fashion, instead of the more typical approach of starting with the overall figure. Though the authors discussed these findings from an executive functioning (i.e., deficit) framework, the participants' approach to the task could also reflect WCC. Indeed, during the memory condition (after three minute delay), children with autism obtained lower scores than the control group, tending to remember only details, instead of the outlines of the figure. From these results, it then seems that memory demands exacerbated the organisational deficit or tendency for featural processing. If the stimulus was encoded in a detail-oriented fashion, it made it very difficult subsequently to organise this information for output in an accurate way. Kenworthy et al. (2005) corroborated these findings with a quantitative analysis of organisational approach to the ROCF (copy condition) based on the developmental scoring procedures created and validated by Bernstein and Waber (1996). To control for graphomotor demands, Kenworthy and colleagues (2005) completed within-subject comparisons of performance on the Beery-Buktenika Test of Visual-Motor Integration with the organisation component of the ROCF in children with high functioning autism or Asperger's syndrome. Organisation scores were significantly worse than expectations based on overall visual-motor integration skill, adding quantitative evidence to the qualitative findings of Prior and Hoffman (1990). This was further corroborated in a study by Booth, Charlton, Hughes, and Happé (2003) in which participants were asked to copy from a model figures such as a house or a snowman. Boys with autism exhibited a more detail-oriented processing style than did TD boys or boys with ADHD as demonstrated by increased likelihood of initiating their drawing with a feature, the presence of fragmentation in their drawings, and general violation of configuration. Accordingly, in another study comparing individuals with high-functioning autism and matched TD controls, Mottron, Belleville, and Ménard (1999) examined graphic reproduction for objects versus non-objects and for possible versus impossible figures (which were incoherent at only the global level). Similar to previous findings, this study documented a bias toward drawing features (versus configural aspects of the non/objects) during the initial copy phase in the group of individuals with high functioning autism. Moreover, for individuals with autism impossibility imposed fewer constraints on their ability to copy a figure than it did for the TD controls. That is, TD controls took longer to copy impossible than possible figures, while individuals with autism had comparable copy times for both conditions.

2.1.3 Verbal-Semantic Coherence

Studies exploring coherence issues in ASD have not been limited to the visuospatial domain; processing of meaning in verbal material has also been investigated. Results from these studies suggest that meaning is extracted in ASD at the level of single words, but is not automatically constructed when stringing together words, that is, for word lists in which all or subsets of these words are semantically related, or at the level of sentences and narratives (e.g., Frith & Snowling, 1983; Kenworthy et al., 2005). For example, the meaning of a sentence determines the pronunciation of an ambiguous word in the Homograph Test (Snowling & Frith, 1986; Happé, 1997). This is demonstrated using "tear" in the following sentence: "In her eye, there was a big tear" versus "In her dress, there was a big tear." Children with autism often fail to utilise preceding sentence context for determining pronunciation (Snowling & Frith, 1986; Happé, 1997; Lopez & Leekam, 2003). In an extension of this work, Jolliffe and Baron-Cohen (1999) documented deficits in local coherence amongst high functioning adults with autism or Asperger's syndrome when tested with homographs, inferential reasoning, and ambiguous sentences requiring context to determine meaning. Moreover, when individuals with ASD were asked to choose the most appropriate bridging inference amongst competing alternatives, they often failed to do so, instead choosing less coherent options. Evidence for difficulty in striving for central coherence in this population was further shown in this study, as people with ASD failed to utilise context to interpret an ambiguous sentence read out to them (Jolliffe & Baron-Cohen, 1999). Perhaps the most telling result from Jolliffe and Baron-Cohen's study was the convergence of results, since performance on these three tasks was correlated, implying a unifying force behind the results obtained, presumed to be WCC. Happé and Booth (in preparation) recently developed a sentence completion task, which also measures children's use of previous context within a sentence, in which the child is asked to complete a sentence stem. For example, in the sentence stem "you can go hunting with a knife and…" the child can respond at a local (e.g., fork) or global (e.g., gun) level. Again with this task, children with autism tend to respond preferentially at the local level (Happé & Booth, in preparation).

A final area of evidence for WCC in the verbal domain comes from studies of reading skill and ability in ASD. It has been robustly demonstrated that individuals with ASD often possess intact, even superior, decoding skills relative to their reading comprehension level (Frith & Snowling, 1983; Snowling & Frith, 1986). Indeed, hyperlexia is common amongst individuals with ASD. Generally, hyperlexia can be defined as exhibiting decoding skills that are far above expectations based on the mental age-level of the child and when compared to reading comprehension level. The disproportionate co-occurrence of hyperlexia and autism (Grigorenko, Klin, & Volkmar, 2003) further corroborates a difficulty with verbal central coherence, since decoding benefits from attention to constituent parts while comprehension requires integration of elements occurring in a sentence or phrase. In alphabetic languages, learning to decode involves breaking down the whole word into its constituent parts; this may be aided by detail focus. Despite the convergence of data, it is important to point out one caveat; this line of research demonstrates consistent processing of meaning at select, often low levels in ASD. So, it is not accurate to say that individuals with ASD do not process information for meaning at all; rather, they seem to do so at the smallest meaningful levels (e.g., words at the semantic level), and they can process for global meaning, if directed to do so (e.g., Instructed Homographs Test: Snowling & Frith, 1986).

The ability to organise information efficiently (e.g., by relating items semantically) has been investigated in a variety of ways in the autism literature, although the relevant authors do not always invoke central coherence as their theoretical framework. The first study of verbal organisation in the autism literature, conducted by Hermelin and O'Connor (1967), examined the ability of individuals with autism and individuals with MLD to remember typically structured (i.e., grammatically correct) sentences versus word strings composed of randomly ordered words (all composed of single syllable words and ranging from three to eight words in length). In a second study, these researchers examined the ability of these two groups of children to utilise semantic cues to assist retrieval of word lists. In both instances results suggested that children of comparable cognitive ability were more likely than children with autism to benefit from semantic information at recall. Similarly, Tager-Flusberg (1991) demonstrated that during free recall, children with autism remembered an unrelated series of words little better than a series of related words, unlike the matched (on verbal mental age) control group of children with MLD and typical development. However, when provided with cued recall, the performance of children with autism reached similar levels to that of the control group. Minshew and Goldstein (1993) utilised the California Verbal Learning Test to examine word list learning in a group of adults with autism. Evaluation of every index of performance was completed, revealing six discriminating variables, all dealing with free recall or semantic clustering. Indeed, these results are consistent with a deficient ability to organise information in the typical fashion. Mottron, Morasse, and Belleville (2001) examined encoding and retrieval cues (none vs. phonological vs. semantic) in word list learning for high functioning individuals with autism and verbal IQ matched TD controls. Results indicated that, unlike TD individuals (for whom semantic cues were most effective), those with autism benefited equally from phonological and semantic cues at retrieval. This adds further to our knowledge of how verbal information may be organised for people with autism; indicating more superficial encoding than is typical, which may assist in explaining some semantic deficits. Finally, Toichi and Kamio (2002) investigated long-term verbal memory and the "levels-of-processing effect" in autism, and consistent with other studies, they found that individuals with autism were less likely to utilise semantic strategies to aid recall.

Perhaps the highest level at which coherence can be obtained within the verbal domain is at the story or narrative level. Inference making, above and beyond comprehension of the story, is one way to examine this absorption of meaning from the story, and has been shown to be poor in adults with ASD (Rumsey & Hamburger, 1988; Jolliffe & Baron-Cohen, 2000). In terms of ability to remember narratives, a study by Rumsey and Hamburger (1990), involving men with autism, men with dyslexia, and TD men, revealed autism specific deficiency in immediate recall of small narratives, whereas their immediate recall of digits was comparable to that found in the TD controls and better than the performance of the dyslexic men. These results provide additional evidence that memory demands exacerbate organisational deficits, as was found when participants with ASD were asked to draw the ROCF from memory. Seeking to extend this area of research, Jolliffe and Baron-Cohen (2000) devised a novel measure of linguistic coherence by asking adults with autism, Asperger's syndrome, or typical development to arrange sentences in a coherent fashion so as to make a short story. Unlike the TD participants, the individuals in the two clinical groups struggled to arrange sentences to complete a story in a coherent fashion. Within and between group comparisons were also made for performance on a control task in which temporal cues allowed for the ordering of sentences. Individuals with ASD performed comparably to controls in this condition but, in contrast to the control group, their performance was much better in the temporal condition than in the coherence (with no temporal cues) condition.

2.1.4 Negative Findings

Despite the persuasive set of studies documenting evidence of WCC across domains in ASD, there is a small set of studies that documents intact central coherence, notably restricted to the visuospatial domain. Ozonoff, Strayer, McMahon, and Filloux (1994) administered the Navon (1977) task (as described in the "Perceptual Coherence" section of this chapter) to assess local versus global processing in people with autism, Tourette's syndrome, or typical development. Results revealed that similar to both control groups, people with autism processed the global forms (i.e., larger letters) first, with minimal interference effects induced by the local, small letters. Similarly, utilising the same type of task, Mottron, Burack, Stauder, and Robaey (1999) found that people with autism demonstrated a global advantage in both congruent and incongruent conditions. Unfortunately for the validation of these results, the Navon task has been shown to be quite sensitive to alterations in methodology, such as the size of the global and local stimuli (Kimchi, 1992) and the exposure duration (Navon, 1977); thus, producing variable results across studies, including those positive results reported in the "Perceptual Coherence" section of this chapter. Moreover, work by Plaisted and colleagues (1999) discussed earlier in this chapter extended this research in the field of ASD by demonstrating that indeed there is interference of local to global stimuli within a divided attention task, but within the context of a selective attention task, interference effects were not observed. This has profound implications for understanding the present negative findings. Plaisted et al. (1999) have effectively demonstrated that when primed to process information globally, many people with ASD can do so; however, when left to their own volition, many people with ASD preferentially process information in a piecemeal fashion. This idea fits nicely with Happé's (1999) reformulation of WCC, implicating WCC as a cognitive bias or style, not a cognitive deficit.

Ropar and Mitchell (1999) sought to replicate Happé's (1996) finding of lowered susceptibility to illusions amongst individuals with autism, while altering the stimuli and response format. In contrast to Happé (1996), they developed a computerised procedure whereby the participants could alter the physical properties of stimuli (e.g., line length) within four visual illusions until they appeared similar. Results over a large number of trials revealed a systematic vulnerability to visual illusions in both the autism/Asperger's syndrome group and the matched control group. In a further experiment, Ropar and Mitchell (1999) aimed to replicate the findings of the original study by Happé (1996), by remaining faithful to her procedures. Again, despite utilising a verbal response format of "same" or "different" and stimuli on cards, a la Happé (1996), results revealed no differential susceptibility to visual illusions between the ASD group and the matched control group. However, it should be pointed out that utilising this original format, fathers of boys with an ASD showed better performance on visual illusions than the fathers of boys with dyslexia or fathers of TD boys (Happé et al., 2001). Nevertheless, Ropar and Mitchell (2001) later returned to the issue of visual illusion effects in ASD, through a replication study and through correlational analyses with prototypical measures of visual coherence. The results corroborated their earlier study, in that individuals with autism and the matched control groups were approximately equally susceptible to illusory effects. Moreover, correlations between visual illusion task performance and performance on prototypical measures of visual coherence were nonsignificant for the most part, indicating that factors unrelated to visual coherence may be operating and necessary when perceiving visual illusions. The reason for this discrepancy is unclear, but the weight of the evidence suggests that people with ASD are not different from comparison groups in perception at this level.

In a small-scale study, Rodgers (2000) investigated visual perception in a small group of individuals with Asperger's syndrome (n=8), in an effort to characterise the pattern of assets and deficits as consistent with WCC theory or with hierarchisation theory (Mottron & Belleville, 1993, 1995; see the "Alternative Theories" section of this chapter for further detail). A TD control group was utilised to compare performance across the following tasks: Block Design, EFT, a Navon-type task, and an Impossible

Figures task. Based primarily upon comparable group performance on the Block Design and EFT and results from the Impossible Figures task (significantly more errors in the Asperger's group), Rodgers tended to favour the hierarchisation model of visual perception in ASD. In addition to limitations of the Navon-type task, as delineated above, the author rightly acknowledges further caveats when interpreting these results. For one, a lack of superiority on the Block Design and EFT could be due to a number of factors; for example, small sample size and constrained IQ range (i.e., with lower IQs, the local advantage and therefore unexpectedly good performance is more noticeable). Moreover, the use of a sample of individuals with Asperger's syndrome to investigate visual perception generalisable to all ASD may be misleading. A body of evidence, albeit controversial, exists which supports relative deficits in visuospatial functioning, as compared to verbal functioning, in individuals with Asperger's syndrome (i.e., a nonverbal learning disability), contrasted with the opposite pattern observed in high-functioning autism (Klin, Volkmar, Sparrow, Cicchetti, & Rourke, 1995). Furthermore, poor performance on the Impossible Figures task could be due to factors unrelated to global-local information processing. For example, anecdotal evidence from caregivers of individuals with autism suggests difficulties in depth perception, and this aspect of visual perception is quite important to the discrimination of possible and impossible figures. Similarly, Burnette et al. (2005) failed to replicate earlier studies when they did not find an autism superiority on the EFT. However, there were a number of difficulties with this study, including use of a categorical scoring scheme for assessing time to find the hidden figure (i.e., one point for figures located in less than 30 seconds and two points for figures located in less than 20 seconds). This is particularly noteworthy on the EFT, since past findings have relied on differences in actual time to find the hidden figure, rather than accuracy alone. In general, using categorical scoring systems has the advantage of limiting the effect of extreme scores, but, used in place of continuous data, it may constrain variance and therefore limit the potential to detect group differences and interindividual scatter. Indeed, the mean scores for both groups approached ceiling performance, making interpretation of these findings more difficult.

Finally, amongst these failures to document WCC in ASD, Brian and Bryson's (1996) attempt to validate the "less capture for meaning" phenomenon may be the most difficult to account for. These investigators utilised a modified version of the EFT, in which there were multiple contexts from which to disembed (meaningful, abstract, or fragmented), to assess adolescents and adults with autism or pervasive developmental disorder and two matched control groups; one matched on receptive language skills and the other matched on nonverbal ability. Results did not reveal the expected autism superiority in the ability to accurately and quickly locate the hidden figure. Furthermore, disembedding was slower within meaningful than non-meaningful contexts for both groups. This finding is more difficult to explain than those from the other studies and only reiterates the need for more replication studies and, more broadly, for further delineation and specification of WCC theory.

At first glance, this series of negative findings may seem to represent a challenge to the validity of WCC theory. However, Brian and Bryson's results aside, the tasks on which most of the negative findings have been based (e.g., the Navon-type task) may be considered somewhat artificial, perhaps lacking external validity to real-life experiences of people with ASD. Large letters composed of smaller letters is only somewhat analogous to the configural processing necessary to derive meaning from our everyday environment. Everyday stimuli are not limited to such miniscule levels of complexity. In this sense, the EFT has more external validity than a Navon-type task. Moreover, the hierarchical information present in our everyday environment often provides exponentially greater information as you ascend levels, unlike the artificial and one-to-one relationship present in and across levels in the Navon-type task. Indeed, it may even be argued that the use of the Navon task to examine hierarchical processing is somewhat inconsistent with the spirit of Frith's (1989) original formulation. Seeking meaning in stimuli, and in fact utilising an inherent cohesive force to bring together smaller pieces of information for higher-levels of meaning, may be most consistent with Frith's original ideas. In the example of a large "Y" composed of many, smaller "T"s; the large "Y", despite its relative size, does not connote a higher-level of meaning just because it is made up of many constituent, but equally meaningful parts (i.e., the letter "T"). In other words, one could argue that in this type of task, on which many of these negative findings are based, the whole is not greater than the sum of its parts.

2.1.5 Universality and Specificity of Weak Central Coherence

One important question facing all theoretical accounts of autism is whether the postulated characteristics are universal amongst affected individuals and whether they are specific to autism. Based on the limited data available on WCC and autism, studies (Jarrold & Russell, 1997; Scheuffgen, 1998) suggest that WCC is not universal amongst individuals with autism. Happé and Frith (2006) provide two reasons why this is unsurprising: 1) individual differences findings from other cognitive accounts of autism (i.e., theory of mind and executive function) also fail the universality test and 2) there are limitations in measurement (i.e., many ways and reasons an individual may pass or fail any one task). Nevertheless, it is still impossible to know what proportion of the ASD population may be characterised by WCC.

The question of whether this cognitive style is specific to autism has a stronger empirical basis from which to draw answers, though rarely are the comparisons made within the context of the same study. Individuals with schizophrenia, William's syndrome, depression/anxiety, and right hemisphere damage have all been shown to demonstrate a local processing bias. For example, schizophrenia has been associated with a favoured local processing bias (e.g., Johnson, Lowery, Kohler, & Turetsky, 2005), while individuals with William's syndrome have been noted to take a piecemeal approach to drawings (e.g., Farran, Jarrold, & Gathercole, 2003), though they also show a general deficit in visuospatial processing. Mood may also affect global-local processing, with at least one study (Basso, Schefft, Ris, & Dember 1996) showing that an index of positive mood was associated with more globally-oriented processing, while separate indices of anxiety and negative mood were associated with a more local orientation. Given that anxiety and depression are commonly reported amongst individuals with ASD (Kim, Szatmari, Bryson, Streiner, & Wilson, 2000), an unresolved issue is whether these behavioural features may play a role in the preferred featural processing style of individuals with autism. Finally, developmental right hemisphere damage, as opposed to developmental left hemisphere damage, has been shown to result in tendencies toward piecemeal strategies in drawing tasks, such as the ROCF (Akshoomoff, Feroleto, Doyle, & Stiles, 2002). Despite these converging data demonstrating local processing biases amongst a number of clinical groups, only one study to date has directly compared individuals with autism to another clinical group, in this case ADHD, on measures of global and local processing (Booth et al., 2003). In addition to the autism specific local approach to a drawing task reported earlier in the "Visuospatial Coherence" section of this chapter, Happé and Booth (in preparation) showed that boys with ADHD do not make the same sorts of local errors on a sentence completion task, as was commonly noted for the boys with autism.

2.2 Alternative Accounts

Since Frith's early conceptualisation of WCC, a number of alternative theories have been proposed to account for the same body of data, to address possible mechanisms underlying this largely descriptive account, and/or to address the limitations of this account.

2.2.1 Hierarchisation Deficit (Mottron & Belleville, 1993, 1995):

These authors propose that both local and global processing are intact in autism, but there is an abnormality in the interaction between these two levels. Thus, global advantage effects, as seen in TD people, are expected to occur, but global interference effects are expected to be absent for individuals with ASD. Indeed, the case study of EC (Mottron & Belleville, 1993) supported this contention and even extended it, since he exhibited local interference effects, making far fewer local than global errors in the context of incompatible Navon stimuli. However, as Plaisted et al. (1999) aptly point out, EC's performance was compared to a pooled mean of six TD control participants, for which no interference effects were noted (i.e., the expected global interference effect did not occur). This then makes EC's performance, specifically the local interference effect, difficult to interpret. More to the point, it is unclear from the study's results whether this effect occurred due to superior local processing or inferior global processing. Another significant limitation of this theory as compared to WCC is that unfortunately, hierarchisation theory has not been extended beyond the visuospatial domain and therefore, does not speak to verbal-semantic oddities exhibited by individuals with ASD. Moreover, contextual processing difficulties in ASD are not addressed in this theory, which focuses solely upon an abnormality in processing of information in the hierarchy from local elements to global configuration. More recently, this has been reconceptualised as Enhanced Perceptual Functioning (EPF) (Mottron, Dawson, Soulières, Hubert, & Burack, 2006). In essence, whereas WCC views consistent documentation of good featural processing in ASD as due to favoured local (vs. global) processing, the EPF account views these findings as indicative of enhanced perception of local features (see Chapter 3 for expansion of this topic).

2.2.2 Reduced Generalisation (Plaisted, 2001):

Within this theoretical account, Plaisted argues for an alternative account of the findings noted in the field of WCC. She specifically postulates that people with autism have a reduced ability to note similarities between stimuli, but an enhanced ability to discriminate between stimuli. The basis for this argument arises from a series of studies conducted by her research group (O'Riordan & Plaisted, 2001; O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001; Plaisted, O'Riordan, & Baron-Cohen, 1998). For example, Plaisted and colleagues (1998) found that within the context of a perceptual learning task people with autism processed the unique elements of stimuli well and the common elements relatively poorly, which stands in complete opposition to findings in the TD control group. Moreover, a later study from this group (O'Riordan et al., 2001) confirmed an autism superiority in visual search, whether the participant is asked to find unique features or a conjunction of features. The Reduced Generalisation theory has exciting possibilities and requires further experimentation to delineate its exact role in cognitive findings for ASD. Currently, this theory cannot account for higher-level findings, such as difficulties in contextual processing; however, it does possess significant strengths, such as its economy of explanation, in the documentation of a rather low-level idiosyncrasy that might be mapped onto neural network models/explanations.

2.2.3 Disorder of Complex Information Processing (Minshew, Goldstein, & Siegel, 1997):

Minshew and colleagues devised this hypothesis after examining the neuropsychological profile of a large group of adults with high-functioning autism. A single, unitary deficit was not documented; instead, these authors advocate the position of Goodman (1989), among many others, in which autism is likely the result of multiple primary deficits. Specifically, their results reveal general sparing of visuospatial skills, in the face of deficits within and across domains directly related to the increasing information-processing demands of the tasks. Unfortunately, the external validity of this hypothesis to all ASD is questionable, given that all testing was completed only with individuals with high functioning autism, not Asperger's syndrome, since these and other non-autistic individuals with ASD were excluded. Furthermore, all testing was completed on adults, which may prove problematic on a number of levels (e.g., neuropsychological/brain-based) when seeking to describe a developmental disorder. Unlike WCC, this hypothesis cannot address areas of absolute strength and/or savant skills. It only speaks to the areas of the neuropsychological profile that may be intact or preserved. And, finally, perhaps most troubling, this hypothesis represents a description, not an explanatory framework predicting or elucidating causal mechanisms. Indeed, complexity is not an easily quantifiable construct, though a later neural model (Belmonte et al., 2004) indicates that complexity may equate to requirements for integration across several brain regions.

2.2.4 Extreme Male Brain Theory (Baron-Cohen, 2002):

Building on the early writings of Hans Asperger (1944), Baron-Cohen (2002) developed the Extreme Male Brain Theory of autism. This model defines the "male brain" and "female brain" psychometrically, that is, based on the extensive research findings regarding gender differences in cognition. As a group, women outperform men on measures of empathy, social judgement, ideational fluency, verbal fluency, fine motor coordination, and so on, while men exhibit superior performance on tasks measuring mathematical reasoning, finding a part within a whole, mental rotation, some spatial skills, and so forth. Male-brain types are considered to be more developed in terms of folk physics or "systemising" but less developed in terms of folk psychology or "empathising" and vice versa for the female-brain type. Broadly speaking, systemising is understanding "closed" systems and their logic, including mechanical, constructional, mathematical, and spatial skills, while empathising encompasses emotional processing and "mind reading", that is, the ability to attribute mental states to oneself and others allowing one to make sense of and predict others' behaviour. An individual may have neither a male nor a female brain type (i.e., fall between the two extremes) and designation of this type is not dependent on one's chromosomal gender. Findings from a series of studies by Baron-Cohen and collaborators (e.g., Baron-Cohen & Hammer, 1997; Baron-Cohen, Wheelwright, Spong, Scahill, & Lawson, 2001; Lawson, Baron-Cohen, & Wheelwright, 2004) and others (e.g., Binnie & Williams, 2003) have demonstrated that indeed individuals with autism and Asperger's syndrome demonstrate an extreme form of the psychometrically-defined male brain in that they perform well on tasks of folk physics and poorly on tasks of folk psychology. However, this account cannot explain the verbal deficits highlighted above (e.g., failure to utilise context when pronouncing homographs and failure to utilise organisational strategies to learn word lists, etc.) and assessment of systemising has been largely via self-report, with a folk physics test (Baron-Cohen et al., 2001) and a test of code-breaking (Lawson et al., 2004) the lone exceptions. On the other hand, significant strengths for this theoretical account are its attempt to tackle the issue of male overrepresentation in ASD and underlying motivation for engaging in restricted interests and repetitive behaviours, nontrivial issues largely ignored by other theories.

2.3 Central Coherence and Savant Skills

It has already been noted that WCC goes some way towards explaining "islets of ability" in ASD, such as the ability to notice subtle changes in the environment or facility with jigsaws. However, how does this theory address the extreme form of cognitive strengths in autism, so-called savant skills? A small group of studies has directly or indirectly addressed this question. In an elegant series of studies, Heaton (2003) characterised the processing of musical information in autism as qualitatively different from that found in typical development. Superior ability to associate a pitch with a picture for later recall was noted in the autism group, but chord disembedding performance by children with autism was better in one condition and equivalent in another to that observed in the matched control group, depending upon the experimental paradigm utilised. These findings dovetail with those from other groups. When comparing performance between a group of high functioning individuals with autism and a matched control group in their ability to make same-different judgments of pairs of melodies, Mottron, Peretz, and Ménard (2000) found similar results to Heaton (2003), suggesting intact global musical processing. However, individuals with autism were better than controls at detecting changes in contour-preserved, but featurally modified melodies, suggesting a featural bias in the domain of music. A later study by Bonnel and colleagues (2003) showed enhanced pitch discrimination abilities in autism, indicating good feature level processing in music. In perhaps the most significant study for better understanding musical savant skills in ASD, Heaton, Hermelin, and Pring (1998) demonstrated stable and superior memory for exact pitches in ASD. In the experimental task, participants were asked to pair a picture with a tone in an associative learning paradigm. Heaton and colleagues indicate that an information-processing bias favouring pitch over melodic information may predispose individuals with ASD to acquire absolute pitch (AP) much more commonly than is normally the case. Heaton et al.'s findings fit well with the broader AP literature in which featural processing was linked to AP in the early years (Takeuchi & Hulse, 1993). A powerful argument was then put forward connecting these data to the development of savant musical skills in individuals with ASD. It may be that AP then serves as a necessary (but, alone insufficient; Heaton, Pring, & Hermelin, 1999) precursor for the development of savant musical skills; every musical savant so far identified has possessed AP (Miller, 1989). Although, the weight of evidence indicates that featural processing of music is good, if not enhanced in ASD, at least one study indicates that music may not be processed well on a global level. Foxton et al. (2003) found that individuals with autism, unlike typical controls, did not exhibit global interference during detection of pitch change under conditions in which other local elements (e.g., absolute pitch and timing) were mismatched, indicating poor global processing of music.

In art skills, detail focus may be important as well. For example, Mottron and Belleville (1993) studied a savant artist who utilised a relatively piecemeal approach to his drawings, especially when contrasted with the approach of a control subject, a professional draughtsman, who began his drawings with outlines before progressing to details or featural elements. Pring, Hermelin, and Heavey (1995) found superior block design performance for both savant artists with autism and artistically gifted individuals without a disability. Documenting this segmentational style of processing in both artistically gifted groups implies that the detail-focussed cognitive bias present in ASD may also be responsible for the overrepresentation of savant skills. Consistent with this idea, Cox and Eames (1999) studied two savant artists with strikingly dissimilar drawing styles, but found that performance on the EFT was elevated in both cases, demonstrating a common ability to focus on local elements.

A compelling argument has also been put forward to delineate the relationship between a detail-focussed processing style and savant skills in calendar calculation (Heavey, Pring, & Hermelin, 1999) and in mental arithmetic (Heavey, 2003). Heavey and colleagues (1999) explain that dates can be viewed as "fragments" of the calendar, which may hold particular fascination for certain individuals, especially those with autism (e.g., consider the frequently mentioned early interest in birthdays as reported by parents). Given the evidence above for segmentational facility in individuals with ASD, combined with the idiosyncratic interest in calendar information, the stage is set for the possible development of calendar calculation skill. Happé and Frith (2006) have also pointed out that task success could be achieved by local instead of global or truly "configural" coherence. Indeed, these authors provide the example of stringing together calendar facts for calendar calculation as an index of local coherence (somewhat akin to grammatical processing in language), something savants with autism are good at doing. In terms of arithmetic ability, Heavey (2003) notes that a cognitive style characterised by field-independent processing is a known correlate of mathematical ability (Benbow, 1988). The tendency towards segmentation is prevalent amongst mathematical savants; many tend to proceed by breaking down operands into their respective factors or into smaller integers. Indeed, the present author has noted that an arithmetical savant with whom he has worked displayed a propensity for segmentation of larger numbers into smaller, but equivalent, chunks to facilitate calculation. Moreover, this proposition also fits with evidence from prime number calculating savants. Anderson, O'Connor, and Hermelin (1998) noted that one savant had discovered the Eratosthenes method in which arriving at a decision as to whether a particularly large number is prime can be deduced by breaking down the number into all constituent prime numbers up to the square root of the number and testing for a remainder.

A number of case studies of savants, though not explicitly making the connection, contain hints of evidence of weak coherence. For example, Stevens and Moffitt (1988) found that an individual with exceptional mental calculation abilities displayed borderline impairment in his ability to integrate visual information holistically, as required by the Hooper Visual Organisation Test. Lucci, Fein, Holevas, and Kaplan (1988) also demonstrated many characteristics of WCC in their case study of Paul, a musically gifted boy with autism. He excelled on block construction, puzzle assembly, and paired associate learning tasks, while his approach to the ROCF was quite disorganised, with a piecemeal approach. Moreover, his memory for short narratives was quite poor, standing in stark contrast to his excellent rote memory for discrete pieces of information.

Although these findings across studies and savant domains indicate a strong link between WCC and savant skills, it should be noted that many of these same findings have also been used to support the EPF alternative account. The EPF and other theoretical perspectives are covered in more detail in Chapter 3.

2.4 Summary and Conclusions

Taken together, the reviewed studies implicate within ASD a consistent tendency across modalities to favour details over configural information. However, it seems that individuals with ASD do not demonstrate WCC at all levels. Based on the current evidence, at what may be considered some of the smallest meaningful units, such as words in language or simple objects in visuospatial perception, people with ASD process information in a typical fashion, but when asked to string together these units, a featural bias occurs, resulting in WCC. Studies, such as work by Frith and Snowling (1983) showing that people with autism could read for meaning when instructed to, and despite their bias for more superficial processing, validate WCC as a cognitive bias or style rather than a deficit.

WCC theory, unlike conventional deficit-based accounts, addresses cognitive strengths in ASD. Indeed, this theory may go some way, if not completely, towards explaining "islets of ability" in ASD, such as facility in completing jigsaw-like tasks. However, its capacity for explaining the extreme levels of ability, that is, savant skills, is less clear, though the limited data so far appear to support the notion that WCC characterises the cognitive style of variously skilled savants. A brief but thorough review of the history and current knowledge base surrounding savant skills may serve to further elucidate the nature of these skills and to stimulate testable hypotheses regarding their potential underlying cognitive mechanisms.

Chapter 3: Savant Syndrome

The following chapter reviews research on the savant syndrome and also attempts to address current outstanding issues in the extant literature, particularly those that provide a rationale for the present thesis. Instead of approaching the chapter by examining separately each savant skill area, this review seeks to uncover consistent trends in findings and identify gaps in the literature, by utilising a cognitive neuropsychological framework.

3.1 Brief History of the Savant

Savant syndrome, despite its rarity, has been well documented in the medical and psychological research literatures for well over a century. In possibly the earliest identified case, a German magazine reported the story of a farmhand mnemonist in 1751 (Foerstl, 1989). However, Down's lecture to the Medical Society of London in 1887, in which he discussed a series of cases of individuals with disabilities who nevertheless displayed remarkable skills, began the still continuing inquiry into how and why savant skills emerge. Among their most important functions, this and other studies helped to establish the range of savant skills and their exceptionality. For example, in his 1914 book, *Mental Deficiency*, Tredgold delineated the special aptitudes present in a group of 20 psychiatric patients. The list of skill areas resonates with those documented at present in the savant literature: calendar calculation, lightning mental calculation, musical abilities, mechanical skills, and visual artistic abilities. He also described such talents as remarkable in comparison to the population at large (not just compared to other patients); thus, highlighting the salience and potential importance of such skill development.

The earliest documented cases of savants provided largely descriptive accounts of individuals then described as "idiot-savants". For example, Jebediah Buxton (b. 1702, reported by Smith, 1983) showed slow but impressive mental calculation abilities (for review, see Heavey, 2003), Thomas Wiggins (b. 1849, described by Southall, 1979, 1983) was an accomplished concert pianist (see Miller, 1989) and Gottfried Mind (b. 1768) drew such realistic and detailed pictures of cats that he became known as "The Cat's Raphael" (Hindermann, 1982). Because severe intellectual impairment was documented in these individuals, the unexpected presence of outstanding skills aroused significant interest. This juxtaposition of skill and impairment remained a question of key theoretical interest for many years, as it was believed that the "idiot-savant" might help elucidate the nature of intelligence.

These contributions were significant in bringing cases to the notice of scientists and therefore subjecting them to empirical scrutiny. Perhaps the greatest strides in applying a rigorous scientific methodology to studying savant skills have been made in the last twenty years, due primarily to the concerted research efforts of Neil O'Connor and Beate Hermelin and their many collaborators. These studies marked a sea change in approach to the study of savant skills, not only by bringing an empirical focus to this area of inquiry, but also by initiating the first group studies of the savant syndrome. These researchers proceeded strategically, examining skill area by skill area, comparing savants to cognitively matched controls and similarly skilled individuals without disabilities. Much of this research will be reviewed in the following chapter. Consistent with these efforts, interest in the savant phenomenon has continued unabated and has culminated in the publication of well over 100 journal articles and book chapters and at least six books (Hermelin, 2001; Howe, 1989; Obler & Fein, 1988; Sacks, 1995; Smith & Tsimpli, 1995; Treffert, 1989) in the English language alone.

3.2 Savant Skills

3.2.1 Defining the Savant

The term "idiot-savant" was first used to describe intellectually impaired individuals with contrastingly outstanding abilities (Down, 1887). Unlike current popular usage, "idiot" was previously a clinical term designating a category of mental retardation based on IQ level (i.e., IQ<25), while savant, derived from the French verb savoir, "to know", means learned individual. More recently, there has been a terminological shift and the terms "monosavant" (Charness, Clifton, & MacDonald, 1988) and more commonly, "savant syndrome" (Treffert, 1989), have come into general usage. Whilst the pejorative connotations of the "idiot-savant" label necessitated such a change, these more current terms do not reflect the paradoxical nature of this intriguing syndrome.

Although rarely mentioned in the extant literature, one unresolved issue is the way(s) in which savant status is determined. This conceptual controversy was reviewed by Miller (1998), who proposed that defining savant status in an individual should be similar to the approach taken for defining a specific learning disability in the United States. Miller endorses a "discrepancy-based model" wherein one compares intra-individual performance across functional domains. In keeping with the specific learning disability model, one example would be the comparison of academic achievement (e.g., reading) with intellectual functioning. Although this may be a useful way of characterising the skill level, it presents its own difficulties. More explicitly, a reliance on standardised tests and therefore a failure to allow for difficulties in comprehension and semantic encoding for those with learning difficulties, have often limited our understanding of intra-individual performance across functional domains. For example, George, one of the calendar calculating twins initially described by Horwitz, Kestenbaum, Person, and Jarvik (1965) and later by Sacks (1985), was unable to multiply 7 x 4, although he could calculate the total number of days in four weeks. Accordingly, the calendar calculating savant described by Ho, Tsang, and Ho (1991) showed poor performance on the Arithmetic subtest of the Wechsler Adult Intelligence Scales but quite good performance on the Stanford Diagnostic Mathematical Test. In the Wechsler Scales, the Arithmetic subtest items are presented as word problems, whereas the Stanford Diagnostic Mathematical Test relies solely upon the manipulation of numbers. These examples highlight the untapped potential of savants, which may go unrecognised due to the domain general nature and presentation format of standardised tests.

Related to Miller's discrepancy-based model is Treffert's (1989) splinter skill category, used for those skills considered remarkable given an individual's overall functioning level. This type of skill would therefore seem to be a natural consequence of the uneven cognitive profile seen in developmental disorders like autism (Happé & Frith, 1996; Rumsey, 1992) and William's syndrome (Bellugi, Lichtenberger, Mills, Galaburda, & Korenberg, 1999). Specific skills (e.g., Block Design performance in autism) might be developmentally on-line; thus fulfilling norms for chronological age, but providing a contrast with overall mental age. Beyond Miller's definition, Treffert's formulation also extends to include talented and prodigious skill levels that reflect comparisons both within and across groups, in the former case to other cognitively impaired individuals and in the latter case to the general population. In the most comprehensive investigation to date, Young (1995) utilised Treffert's criteria for all 51 potential savant participants and suggested that savant status should be reserved for those individuals falling in the talented and prodigious categories. Therefore, Young's study indicates the usefulness of across-group comparisons in measuring savant talent.

Although Miller's (1998) proposal of intra-individual comparisons could be of great utility in determining savant status, utilisation of IQ as the litmus test against which skills may be contrasted presents difficulties for those in whom IQ measures may be misleading, that is, those with uneven IQ profiles. One way to get around this roadblock is to utilise measures of everyday, real-life functioning, such as adaptive functioning, to determine disability status and to subsequently contrast with unexpected skills. This is not purely idle speculation since support for de-emphasising IQ is derived from the observations that between 20 and 30% of individuals with autism score in the average range on measures of IQ, and this figure rises considerably when including other ASD (e.g., Asperger's syndrome). Additional support is provided by Young's large sample of potential savants who showed intellectual impairment at mild to borderline levels in the majority of cases. Moreover, there are reports of individuals with autism who are labelled as savants despite average, or above average intellectual functioning (e.g., Heavey et al., 1999; Young & Nettelbeck, 1995). Finally, adaptive functioning deficits are commonly reported in high functioning, that is, normal IQ, individuals with ASD (e.g. Klin, 2000), thus validating the inclusion of such subjects within the savant category.

Typically, savant skills are demonstrated in a rather circumscribed range of domains, such as calendar calculation, memory, music, art, and arithmetic skills (Hill, 1974). However, there are also reports of savants with prime number identification skills (Anderson et al., 1998; Hermelin & O'Connor, 1990a; Kelly, Macaruso, & Sokiel, 1997), mechanical (Brink, 1980; Hoffman & Reeves, 1979; Tredgold, 1952), and linguistic skills (Dowker, Hermelin, & Pring, 1996; Smith & Tsimpli, 1995). Although general consensus has been reached on the list of prototypical savant domains, other skill areas are more difficult to situate. For example, hyperlexia (for review, see Nation, 1999; Grigorenko et al., 2003) generally involves a significant discrepancy between reading decoding and reading comprehension, with the former being superior (Snowling & Frith, 1986). However, hyperlexia is rarely designated as a savant skill in the extant literature, partly due to developmental factors; this decoding skill eventually ceases to be outstanding because of a natural ceiling on ability. But, in fact, at earlier points in development (usually the preschool years), hyperlexia meets criteria for a skill that is exceptional relative to overall ability (Welsh, Pennington, & Rogers, 1987), and exceptional relative to that of normally developing peers; thus, satisfying requirements of the traditional savant definition. Similar to other savant skills, hyperlexia has been noted frequently in individuals with ASD (Nation, 1999), although it has also been observed in other developmental disorders, especially those involving language and communication abnormalities, such as speech-language impairment (Cohen, Hall, & Riccio, 1997), Williams syndrome (Bellugi, Birhle, Neville, Jernigan, & Doherty, 1992), Turner's syndrome (Temple & Carney, 1996), and idiopathic intellectual impairment (Snowling & Frith, 1986).

3.2.2 Rates of Occurrence

Due to a lack of rigorous epidemiological investigations, the true prevalence of savant skills in ASD, in developmental disorders more broadly, and in typical development is unknown. However, surveys carried out by Hill in 1977, Saloviita, Ruusila, and Ruusila in 2000, and Rimland in 1978 provide important data regarding putative numbers of savants in populations of individuals with intellectual impairment and/or autism. In Hill's study, 107 institutions (out of 300 approached) for individuals with intellectual impairments identified 54 savants, a prevalence rate of approximately 0.06% or roughly one in every 2000 intellectually disabled residents. On the other hand, Saloviita et al. (2000) targeted all institutions in Finland currently serving individuals with developmental disabilities as well as subscribers to the two most widely circulated journals for the field of intellectual impairment, one of which catered to parents. In contrast to Hill's study, the savant skills survey revealed an incidence rate of 1.4 per 1000 individuals in the intellectually impaired population. Unfortunately, neither of these studies separates known (e.g., ASD) from unknown aetiologies amongst the individuals with savant skills, so a significant number could have undiagnosed or unmentioned ASD. Rimland (1978), on the other hand, specifically targeted parents of 5,400 children with autism, and in this case 531 individuals, constituting 9.8% of the sample, were identified by parents as savants. As a result, the discrepancy in findings, at least between the studies by Hill and Rimland, suggests that there is a significantly greater prevalence of savants in populations of individuals with autism as opposed to intellectually impaired individuals. However, it should be noted that the respondents in Hill's study were careworkers, whereas Rimland's respondents were parents, who might have shown a positive bias in reporting their children's skills. Unfortunately, clarity on this issue is not provided by the most recent study (Saloviita et al., 2000) since the informants were a mixture of careworkers and parents.

Another difficulty in accurately determining the co-occurrence of the savant syndrome and autism concerns changes in diagnostic criteria and practice in the last 25 years that have led to a sharp rise in numbers of individuals diagnosed with ASD (Chakrabarti & Fombonne, 2001, 2005). This raises the possibility that many of the intellectually impaired savants described in the past research literature might meet current criteria for an ASD. Moreover, Young (1995) observed that all of the potential savants in her sample showed some characteristic behaviours of autism, although some had never received a formal diagnosis. Case study descriptions of savants with complex patterns of disability (e.g., congenital blindness, intellectual impairment, and language disorder) also frequently make reference to behavioural features commonly associated with autism (e.g., musical savants: Miller, 1989). Finally, social eccentricity and high scores on the Block Design task, both of which characterise ASD, have been reported amongst people who possess AP, even when compared to non-AP musicians (Brown et al., 2003). Taken together this evidence strongly suggests that savant talent is most closely associated with ASD or at least ASD traits. Savant talent is occasionally seen in individuals with other developmental or neurological disorders, though they typically share key behavioural features with autism, such as obsessive, engrossing, and restricted interests (O'Connor & Hermelin, 1991).

3.2.3 Obsessions and Restricted Interests

By definition, individuals with autism show repetitive behaviour and restricted interests (APA, 1994). Although this tendency to engage in repetitive activity in narrowly focussed areas is generally disadvantageous for people with autism in that it gives rise to a restricted repertoire of behaviour and experience, this may not always be the case. For example, if this tendency co-occurs with other cognitive, emotional, and/or physical talent components, it may serve to function as a motivational trait (Simonton, 2001), thereby enhancing the probability of talent emergence. Asperger (1944), who along with Kanner (1943) first described the autistic disorder, proposed that the personality characteristics exhibited by his patients could facilitate high-level skill development. Indeed, one of Asperger's patients was a successful composer. Several lines of evidence support the view that obsessions and restricted interests might play a role in the development of savant talent. O'Connor and Hermelin (1991) investigated restricted and repetitive behaviours in savants and found that regardless of diagnosis, savants demonstrated more of these behaviours than nonsavant controls matched for IQ and diagnosis. Moreover, although individuals with autism represent a relatively small proportion of the intellectually impaired population, the majority of talented, but intellectually impaired individuals have been diagnosed with autism. As alluded to earlier, in cases where savant talents were reported in individuals without autism, they frequently had developmental (e.g., Tourette's syndrome: Nelson & Pribor,

1993) or acquired disorders (e.g., frontotemporal dementia: Miller, Ponton, Benson, Cummings, & Mena, 1996; Miller et al., 1998) that include obsessive behaviours and/or restricted interests as clinical features. Therefore, converging evidence highlights the significance of obsessive and restricted interests in the development of savant talent, both in and out of the context of ASD, which may reflect practice effects and/or WCC.

3.2.4 Characteristics of the Savant Skill Areas

One avenue of pursuit that may give insight into the mechanisms subserving savant skill expression is a closer examination of the skill areas themselves. It is striking that savant skills exist within a limited and recurring group of domains. As previously noted, these include calendar calculation, music, art, mental calculation, and pseudo-verbal skills (including hyperlexia and facility with foreign language acquisition). Therefore, it would be revealing to examine shared aspects of these domains. It may be apparent upon first glance that these domains are predominantly nonverbal, and that even the pseudo-verbal skills are generally free of higher-level linguistic demands. Individuals with hyperlexia are by definition relatively deficient in their reading comprehension and even Christopher, the well-known savant who can easily grasp some aspects of a novel foreign language (O'Connor, Smith, Frith, & Tsimpli, 1994), displays verbal skills primarily in his facility with vocabulary and underlying grammar.

As aptly pointed out in previous research, a second commonality among these domains is their purported reliance upon right hemisphere functioning (Rumsey, 1992; Treffert, 1989). This postulation is significant in supporting brain-based models (e.g., Treffert, 1989) that highlight the importance of right hemisphere compensation (and subsequent hyperfunction?) due to left hemisphere damage/dysfunction. Although promising, this hypothesis is somewhat tempered by findings that aspects of musical cognition, for example pitch and rhythm, are subserved primarily by the left hemisphere (Platel et al., 1997). But this idea may provide leads in elucidating brain-based mechanisms for savant skill presentation in both individuals with developmental disorders and those with acquired neurological damage.

Perhaps the most convincing finding is that all savant skill areas contain high internal structure (Miller, 1989). Indeed, each of the savant domains has rules that govern the application of skills, and previous work (Heavey et al., 1999; Miller, 1989; Nettelbeck & Young, 1996; O'Connor & Hermelin, 1984, 1987a, 1987b, 1990; Sloboda, Hermelin, & O'Connor, 1985) has alluded to the importance of organised, rule-based knowledge in savants. Moreover, the underlying systems for each of the savant domains can be broken down into elemental components and reconstituted to form meaningful wholes. Evidence suggests that both disembedding and reformulation abilities are intact in autism. For example, savant artists apply a local processing strategy in picture production but are nevertheless able to produce output that is globally intact. Thus, while processing strategies are strongly featurally biased, this does not appear to convey a disadvantage within savant talent domains. As mentioned in Chapter 2, Baron-Cohen and colleagues (e.g., Baron-Cohen, Richler, Bisarya, Gurunathan, & Wheelwright, 2003) determined that high functioning people with ASD were particularly good at systemising. According to Baron-Cohen and colleagues, systemising permits the prediction of a system's behaviour. Regardless of the content, a system is defined as "something that takes inputs, which can then be operated on in variable ways, to deliver different outputs in a rule-governed way." This perspective may be complementary to the WCC account in that good local coherence as predicted by WCC may allow for the methodical approach to building up to and better understanding "systems" that are reminiscent of savant domains. However, systemising theory, unlike WCC, offers a perspective on why individuals with ASD possess a drive to master systems, such as taxonomic categories or savant domains like music and numbers. Nevertheless, the relationship between measures (e.g., self-report) of systemising and savant skills has yet to be examined.

Savant skills were long thought to reflect exceptional (rote) memory by savants. While good memory is undoubtedly a piece of the puzzle to better understanding savant performance, the work of Hermelin and O'Connor, among many others, indicates that savant skills may reflect learnt rules, not merely rote memory. For example, calendar savants have been shown to make systematic errors in their calendar calculation (Cowan, O'Connor, & Samella, 2003). Moreover, other work indicates that calendar savants have knowledge of calendar regularities, which are then used in completing calendar calculations (Cowan, O'Connor, & Samella, 2001; Cowan, Stainthorp, Kapnogianni, & Anastasiou, 2004; Hermelin & O'Connor, 1986; Ho et al., 1991; O'Connor & Hermelin, 1984). Performance by savant musicians has also provided evidence of skill acquisition and expression dependent on other, non-memory related processes. Eight keyboardist musical savants and a comparison group of eight typical musicians were asked to replay four and eight chord sequences varying in structure (Miller, 1995). No differences emerged between groups so that as structure decreased so did the participants' ability to replay the sequences. Moreover, this investigation found that when errors were made, savants were more likely than controls to impose structure in the reproduced segments. This implies that savants' performance is not based on simple encoding and retrieval; rather, output will remain faithful to structural rules of the system, even if an exact replica is not reproduced. Other shared characteristics have also been proposed. According to Mottron et al.'s (2006) EPF model (mentioned in Chapter 2 and discussed more fully later in this chapter), focussing on the perceptual level is helpful in all savant domains. Therefore, taking this viewpoint, all savant domains rely on low-level perceptual mechanisms, which cater to the cognitive strengths of savants, particularly those with ASD. The shared characteristics of savant talent domains, such as those highlighted above, may be particularly informative for theories to explain the presence of savant skills in ASD specifically as well as other clinical disorders.

3.2.5 Development of Skills

Savant skills present a paradox to the notions of talent and disability; on one hand, they are reported to be "self-taught", while on the other hand, they are sometimes dismissed as nothing more than the product of relentless practice and over-learning. Turning to this second issue; the role of practice in the development of expertise is a well-researched topic. Ericsson and Faivre (1988) provide startling examples of memory feats attained by TD individuals after extensive practice. For example, one individual, case SF, after 30 months of practicing about an hour a day, several days a week, gradually increased his digit span from seven to over 80 digits. Analysis of strategies revealed that meaningful associations of learned material (digits, in this case) were needed to overcome short-term memory limitations. SF, a long-distance runner, could utilise his knowledge of running times for various types of distance races (e.g., marathon) to assist in encoding this digit information.

Interestingly, the researchers extended their argument and examples beyond memory alone to include skills such as AP. For AP development, they argue that some instruction is required in order to pair a note name to a pitch. However, Heaton et al. (1998) addressed this particular issue in a musically naïve group of children with autism and in a matched control group of TD children. Using a paired learning design, in which a series of pitches was each paired with its own animal picture, after multiple learning trials the testing phase began. During testing, children heard a tone and were required to identify (through pointing to one picture amongst competing options) the animal that went with that pitch. Children with autism, despite having no previous note naming abilities (and therefore no proclivity for practice), were superior to TD controls in identifying the corresponding pitch, suggesting that AP (or at least potential AP) may be a relatively common though hidden skill amongst individuals with autism.

In the only documented case of a TD participant successfully trained to attain AP (Brady, 1970), the emphasis of training was identifying a single tone. Such a piecemeal approach fits nicely with research literature demonstrating a featurally biased cognitive style for people with autism and also with the study by Heaton et al. (1998). Even more revealing for the issue at hand, the Heaton et al. study demonstrates a natural, unpractised aptitude (criteria given by Ericsson and Faivre as necessary to show that performance was not acquired through practice) in autism for the development of AP. The studies above, and others (e.g., Chase & Ericsson, 1981) showing exceptional skill development after extensive practice, are indeed very revealing, but the question remains as to whether they are directly applicable to savant skill development. Extrapolation of these studies' results to savant skills is not necessarily valid. One significant hurdle, yet to be crossed in practice-based studies, is the enrolment of participants with low IQ or other disability in order to equate context of skill acquisition. Just because a TD individual can obtain a specified level of expertise, does not mean that a savant with a much lower IQ has reached this same end point via the same route. Furthermore, Hermelin (2001) aptly points out that practice by an adult over a limited period of time cannot adequately replicate savant skill development with (usually) childhood inception and therefore suffers from the same pitfalls as attempting to apply results of adult-based brain lesion studies to neurodevelopmental disorders.

Savant skills have garnered attention and amazement, not only because of the paradoxical presence of a well-developed skill in the context of disability, but also because of the nature of the emergence of these skills. Some of the most well-known and puzzling cases of savant syndrome have presented spontaneously, that is, they emerged seemingly highly developed, with no hint to their previous existence. Perhaps the most famous example of this phenomenon is Nadia, the girl with autism who suddenly displayed remarkably precocious drawing ability at the age of three (Selfe, 1978). For example, even at age three, her drawings of horses were considered remarkable regardless of group chosen for comparison and were compared favourably to work by Leonardo Da Vinci. Incidentally, Selfe and a colleague, Newson, had rated and categorised over 24,000 "pictures of Mum" by children of various ages for a national competition that later led to an exhibition on this topic. Based on this extensive knowledge, the investigators concurred regarding the exceptionality of Nadia's skill.

The idea of sudden skill emergence; however, is not free from controversy. For example, Leslie Lemke, a musical savant, who is visually impaired and has received a diagnosis of autism, was reputedly another case in point. Initially, Leslie's mother, May, observed a quite sudden expression of his musical talent when he was around 14-years-old. She awoke in the middle of the night to piano playing and was utterly astonished to find that it was her son Leslie. This was the gist of the original story as reported in 1981; however, upon further scrutiny, Darold Treffert (1989) revealed that indeed Leslie had been playing simple pieces on the piano as early as seven or eight years of age and therefore, these skills did not burst upon the scene, as earlier believed. From this pair of anecdotes, it is clear that not all savants reveal sudden onset of a well-advanced skill; however, the exceptional cases that do, are important because they refute claims that savant skills are nothing more than well-rehearsed skills. Even though sudden skill emergence is likely rare, a commonly noted aspect of savant skill development is the notion of their being naïvely learned or "self-taught" (i.e., not formally taught), standing in stark contrast to similar skills in otherwise TD talented individuals.

In summary, although practice may play an important role in talent development (savant or nonsavant) it is insufficient to account for most, if not all cases of prodigious skill, especially the rare cases when skills suddenly emerge with no previous hint of their existence. Moreover, as discussed later in the "Explicit and Implicit Memory" section of this chapter and in Chapter 4, the untaught, sudden emergence of skills argues for strong consideration of implicit learning mechanisms leading to early development of savant skills.

3.2.6 Savant Skills and Intelligence

Because of the striking combination of ability and disability, intelligence theorists must account, to at least some extent, for the savant syndrome. Exhibiting a single or sometimes multiple high-level skills in the context of low IQ presents a paradox. Some investigators have chosen to consider such skills as "unintelligent" by claiming that savant skills are over-learned and/or acquired through rote memory, and thus superfluous to the concept of intelligence (e.g., Howe, 1989). Some investigators (e.g., Hermelin & O'Connor, 1990b) contend that these skills are the product of rule-based (implicit) learning in savant domains, based on findings of high IQ TD individuals failing to master skills displayed by savants. Nevertheless, savants may provide insights into whether a general intelligence factor (Spearman, 1927) should be discarded in favour of a model positing independent, multiple intelligences (Gardner, 1983). Although researchers have attempted both to explain the savant within the context of current models of intelligence (for review, see Nettelbeck & Young, 1996) and to develop new models within which the savant can be situated (Anderson, 1998), there has been something of a change in thinking, questioning whether the savant can indeed inform our understanding of the nature of intelligence itself. It has been suggested that savants do not pose a challenge to current theorising about the nature of intelligence (Nettelbeck & Young, 1996) as their behaviours are not essentially intelligent (Spitz, 1995), but reflect purely localised knowledge (Herrnstein & Murray, 1994). However, data from empirical studies (e.g. Anderson et al., 1998; Cowan et al., 2001; Heavey et al., 1999; Hermelin & O'Connor, 1986; Miller, 1989; Mottron & Belleville, 1993, 1995; Pring & Hermelin, 1993; Pring et al., 1995; Young & Nettelbeck, 1994, 1995) clearly show that these skills are supported by memory and information processing mechanisms that contribute to or underpin general intelligence (Nettelbeck & Young, 1999) and that savant skill performance itself improves as IQ scores increase (e.g., O'Connor, Cowan, & Samella, 2000; Rumsey Mannheim, Aquino, Gordon, & Hibbs, 1992).

Cognitive theorists are also interested in the savant syndrome because of its relevance to the notion of modularity of cognitive function. In his influential book, Fodor (1983) delineated four main features of modules. Modules are cognitive processors in the brain that operate independently, that is, damage to one module should not directly affect the functioning of another module. They are domain-specific, wherein each module can process only one type of input (e.g., faces). Finally, modules are inborn, that is, set up from birth, and they are not under voluntary control. Given these constraints, some researchers have used the case of savant syndrome as a classic example of the modularity, or modularisaton (Karmiloff-Smith, 1998), of certain cognitive functions (Anderson, 1998; Tsimpli & Smith, 1995); cases where select skills (e.g., music) are preserved or even enhanced, while others (e.g., language) are deficient.

Rather than getting caught in the cycle of relegating savant skills as (ir)relevant to the notion of intelligence, depending upon the theory one espouses, an alternative method for examining the theoretical significance of savant skills is to utilise a neuropsychological framework in which a variety of basic cognitive processes are examined.

3.3 Autism and Savant Skills: Cognitive Neuropsychological Accounts

The overrepresentation of autism among individuals with savant skills is considered a nontrivial phenomenon and requires explanation. As previously reviewed in Chapters 1 and 2, psychological theories of autism, such as the executive function (Russell, 1997) and theory of mind (Baron-Cohen, Tager-Flusberg, & Cohen, 2000) accounts, have historically focussed upon and addressed deficits observed in these individuals. One notable exception to this trend, WCC theory (Frith, 1989; Happé, 1999; Happé & Frith, 2006), as reviewed in Chapter 2, directly addresses the question of why splinter and savant skills should preferentially emerge in autism. However, over the years, there have been other accounts attempting to account for savant skill development, particularly in autism.

One promising early perceptual-level account for special skills was put forward by Waterhouse (1988). Her ideas arose in response to the failure of theoretical models of intelligence to account for special skills. Importantly, Waterhouse proposed that special cognitive talents and abilities in savants are qualitatively different from those of typical individuals. She believed that they were separate in source from individual differences in intelligence and therefore did not represent end points of the normal distribution of various skill areas. Specifically, she proposed that special skills derive from a preconscious and specific set of memory and processing mechanisms that facilitate "acutely accurate and extremely extensive representation of visual images and sounds" and allow "the rapid recognition and facile manipulation of patterns involving those visual and auditory representations" (Waterhouse, 1988). According to the model, the savant may both generate and elaborate upon these complex mental representations, but also see or hear complex patterns embedded within relevant visual or auditory stimuli. Similar to the argument made here, Waterhouse highlights the importance of the induction of regularities or of structural elements within various perceptual systems by savants. According to Waterhouse, special skill development is genetically driven and brain-based, via cortical rededication. Presumably, for special skills in the context of autism, areas of cortex (or significant portions of these areas) typically devoted to social-emotional functioning would be reallocated to perceptual pattern recognition. Consequently, this functional rededication would result in superior performance on perceptual pattern recognition tasks and correspondingly poor performance on tasks of social cognition.

Around the same time, Treffert (1989) also proposed a neurologically mediated multi-factor model of savant skills. Brain-based factors included compensatory right hemisphere functioning after left hemisphere damage and reliance upon lower-level procedural memory due to damage to higher-level memory circuitry. The effortless, automatic nature of savant skills and the intact aspects of memory functioning are noted and proposed as necessary but not sufficient for savant skill development. Treffert also notes the restricted range of savant talent domains and postulates that they are mediated (at least to a significant degree) by the right hemisphere. Thus, the importance of the nature of and commonality between these domains is highlighted. An additional element to this model is the focus upon the single-mindedness of savants for the skill area in question. Thus, concentration, repetition, and practice are considered to be important and reinforcing for the maintenance and elaboration of skills. In an attempt to explain the preponderance of savant skills in autism, Treffert drew on research suggesting that right hemisphere functioning (at least as relevant to savant domains) and procedural memory are generally intact in autism. Returning to his subgrouping of savants by skill level, Treffert pinpoints a requisite genetic factor for only the most exceptional (i.e., prodigious) savants. Therefore, while there are multiple paths to the end points of splinter skills or talented level savant skill expression, one does not reach prodigious levels of performance without a significant genetic predisposition. Despite appealing aspects of Treffert's theoretical account, such as delineation of savant skill levels and invoking implicit memory as representative of savant-type memory, several difficulties arise, including the notion of right hemisphere sparing/left hemisphere deficit. For example, the right hemisphere has been linked to areas of difficulty for savants with autism, such as pragmatics (Ozonoff & Miller, 1996) and the left hemisphere has been associated with areas of strength, such as featural processing (Moses et al., 2002).

In the latest theoretical account of savant skill development, Mottron and Burack, originally delineated in 2001, but recently updated (Mottron et al., 2006), outlined a model proposing EPF in autism. According to the EPF model, lower- and higher-level processing mechanisms are dichotomously grouped, with low-level mechanisms being domain specific and neurally-specified while higher-level mechanisms are domain general and distributed across several brain regions and networks. These authors suggest that people with autism show overdevelopment of low-level perceptual abilities, likely due to hyper-functioning of brain regions typically involved in primary perceptual functions, or due to reduced functioning of high-level mechanisms. Thus, it is postulated that splinter and savant skills in autism will involve operations that are largely perceptual, with the proviso that they can include different modalities or the simple operations of associating, combining, and matching on tracks of visual or auditory stimuli. A major strength of this model is that it takes a developmental approach, whereby an early, unspecified cognitive deficit results in an enhanced cognitive operation via compensatory action. This subsequently improved aspect of cognitive functioning becomes increasingly over-trained and heavily practiced, leading to the development of a restricted interest. Moreover, citing evidence of excellent spatial orientation in autism (Mottron & Burack, 2001), these authors conclude that their model has distinct advantages over WCC theory since spatial orientation does not, on the surface, require featural processing. However, this model predicts only one area of talent per savant, which runs counter to findings in the literature, and indeed to one case reported later in this thesis, and assumes that all savant skills are reliant on good low-level perceptual functioning, which may be difficult to explain in some instances (e.g., number and calculation skills). Furthermore, despite its obvious strengths, Mottron and Burack's proposal that savant abilities never include aspects of relative weakness among persons with autism fails to account for several individuals described in the savant literature. For example, Smith and Tsimpli (1995) described a savant who shows outstanding foreign language acquisition abilities, while Dowker et al. (1996) described a savant poet. There are also examples of savants with autism who are very sensitive to the affective dimensions within their talent domain. For example, Richard Wawro, the savant artist described by Hermelin, Pring, Buhler, Wolff, and Heaton (1999), is very sensitive to colour, and in his compositions changes and intensifies colours in order to manipulate overall mood.

One of the deficit-based accounts of ASD, executive dysfunctioning, has also been documented in savants with autism (Steel, Gorman, & Flexman, 1984; Rumsey et al., 1992; Mottron, Peretz, Belleville, & Rouleau, 1999); however, there is an obvious confound as to the specificity of the executive dysfunction. Unfortunately, from the limited evidence, it is unclear as to whether the executive dysfunction is the result of the presence of an ASD, in which these deficits are robustly documented (e.g., Ozonoff, 1995; Rumsey & Hamburger, 1988), or whether it is integral to the cognitive landscape of the savant syndrome. Particularly relevant to the notion of savant talent, generativity or fluency is one aspect of executive functioning that has been demonstrated as deficient in ASD (Dunn, Gomes, & Sebastian, 1996; Turner, 1999). However, as for measurement of memory outside the area of talent, valid assessment of executive functioning, particularly generativity, requires both domain-specific and domain-general assessment. Of relevance here are studies by Ryder, Pring, and Hermelin (2002) comparing savant artists with autism to control groups of TD art students, non-savant individuals with autism, and individuals with MLD. Findings from these studies demonstrate that on tasks of design fluency and visual synthesis, savants with autism showed a fluency deficit as severe as that found in the nonsavant controls with autism. However, on the Torrance Test of Creative Thinking, the drawing output of the savants with autism was more elaborate than that of the two IQ matched control groups (individuals with autism and with MLD), and on the visual synthesis tasks, originality scores equalled those of gifted art students. Thus, while these savants showed a pervasive fluency deficit characteristic of autism, they were nevertheless able to produce highly elaborated and original responses within their talent domain. Also pertinent to the executive dysfunction account, Snyder and Mitchell (1999) proposed that TD individuals are concept-driven and thus cannot access the skills fundamental to becoming a savant. A lack of this typical top-down processing, according to the authors' view, is what allows savants to "have privileged access to nonconscious information and processes" so that they perceive every detail in a percept and "interpret" these percepts without interference from previous conceptually driven knowledge. So far, transcranial magnetic stimulation studies have provided mixed support for this contention (Snyder et al., 2003; Young, Ridding, & Morrell, 2004); therefore, more research is needed to answer this question.

3.3.1 Memory and Cognitive Strategies

One suggestion that has been made frequently is that savants show exceptional rote memory (Hill, 1978). However, if rote memory is defined as the veridical encoding of information, this clearly does not explain savant talents within the classical domains of music, art, and calendar calculation, where greater flexibility in the manipulation of domain-specific information is essential and indeed evident in savants. For example, investigations into the musical memory of savants (Sloboda et al., 1985; Young & Nettelbeck, 1995) show that although long-term memory is good, or indeed exceptional, reproduction of heard material is not verbatim, and reproduction errors preserve the important structural characteristics of the compositions.

Because rote memory is thought to be unusually intact in autism (Happé & Frith, 1996; Rumsey, 1992), one hypothesis (Ho et al., 1991; Young & Nettelbeck, 1994) states that savants with autism, who frequently display circumscribed interests in factual material such as that found in encyclopaedias and calendars, rely heavily on memory-based strategies in completing calendar calculations. Alternatively, such calculations might involve the application of several relatively simple rules based upon regularities of the Gregorian calendar. Hermelin and O'Connor (1986) documented the use of two rules in a group of eight savants, the corresponding months rule and the 28-year rule. The Gregorian calendar contains regularities (although not completely lawful) that may facilitate calendar calculation, such as the same day-date correspondence of certain pairs of corresponding months within a calendar year or the repetition of the calendar template every 28 years. To demonstrate the use of these rules, Hermelin and O'Connor (1986) examined the RT of participants when primed with dates in corresponding months. Because the calendar calculators were faster on the second corresponding month it was assumed that they were utilising this rule to facilitate speed and performance. The documentation of rule use by savants was important in demonstrating that savant skills could not be explained away as merely feats of memory. Nevertheless, the weight of evidence suggests that the most likely explanation involves a combined application of these strategies (Hermelin & O'Connor, 1986; Howe & Smith, 1988).

Findings from investigations comparing savants and TD individuals with talents in the same domain sometimes suggest that similar mechanisms underpin skill in both groups. For example, in a previously mentioned study involving a prime number calculator with autism, Anderson et al. (1998) found that both this individual and a trained mathematician used an algorithm described by Eratosthenes in the 3rd century BC. Similarly, Kelly and colleagues (1997) found that a calculating savant used similar computational strategies to those of normal expert calculators. However, the savant draughtsman described by Mottron and Belleville (1995) clearly used different strategies to controls in graphic reproduction. Although the question of (dis)similarities in cognitive strategies remains unanswered, it is nevertheless clear that savant skills do not rely solely on rote memory but reflect an enhanced or spared ability to represent and manipulate highly organised domain specific information.

On standardised tests of memory, savants generally do not tend to show good levels of performance (Howe, 1989). However, as previously suggested, tests relying on intact comprehension and semantic encoding skills may not be appropriate tools for probing savant memory, especially where there is a diagnosis of autism (Nettelbeck &

Young, 1999). Digit span is sometimes viewed as a measure of short-term memory (Jackson & Warrington, 1986), and some investigators (Duckett, 1976; Spitz & LaFontaine, 1973) have found better subtest performance for digit span in calendar calculators than would be predicted from full scale IQ alone. However, this finding was not replicated in the sample of calendar calculating savants described by Heavey (1997). Similarly, memory performance on tests where stimuli reflect the savant domain has been found to be good in some studies (Heavey, 1997; O'Connor & Hermelin, 1989; Valentine & Wilding, 1994), but not in others (Young, 1995). Despite this lack of consensus, anecdotal reports of savants invariably describe outstanding memory abilities; it may be that methodological limitations, such as reliance on standardised tests, rather than truly unexceptional memory, accounts for this lack of experimental validation. For example, in Young's sample of individuals with savant and splinter skills, 37 of 39 parents reported precocious levels of memory. On a standardized measure, the Wechsler Memory Scales-Revised, Young found elevated performance on the Delayed Memory Quotient, indicating good recall for well-encoded information. Based on these findings, Nettelbeck and Young (1996) suggested that declarative (rote) memory, facilitated by an ability to make associations, is essential for savant skills. Converging evidence therefore suggests that memory is an important cognitive component of savant skill, but does not account fully for these skills.

3.3.2 Explicit and Implicit Learning

It is unclear exactly how implicit learning plays a role in savant skill development. Given that implicit learning, in theory, is dissociable from explicit learning processes (e.g., Rugg et al., 1998), a generally or relatively heightened implicit learning capacity in savants could, in itself, underlie their attraction to and facility with materials in a specific set of domains. Therefore, it could be that an inherent preoccupation with structure and predictability, as would be the case for most, if not all, individuals with autism, would play a prominent role in skill expression, or, it could be due to overexposure to the material in question, which leads to the emergence of awareness and knowledge of its elemental properties. Perhaps, even more likely, it could be a combination of these factors operating to various degrees, depending on the individual in question, but placing parameters on skill development. To this end, Spitz (1995) has proposed that over-learning, at least in the case of calendar calculation, may result in implicit learning of calendar structure, facilitating the development of such skill.

As discussed in Chapter 2, individuals with autism display good rote memory skills on the one hand, while on the other failing to use semantic cues as often as controls to aid recall. In support of the failure to use semantic cues, Beversdorf et al. (2000) showed that people with autism might be less susceptible than control participants to false memory induction in the context of a word list learning task. However, this small study was not replicated by Bowler, Gardiner, Grice, and Saavalainen (2000) when they attempted to induce false memories through a word list learning task in a group of individuals with Asperger's syndrome.

In savants with an autism spectrum diagnosis, language and communication impairments may severely curtail their ability to profit from explicit instruction. Exacerbating these difficulties, intellectual impairment is found in the majority of individuals with ASD (Volkmar & Lord, 1998). Indeed, studies of individuals with intellectual impairment (e.g., Down's syndrome), but without autism, have shown deficits in explicit learning in comparison to controls (Carlesimo, Marotta, & Vicari, 1997) so this difficulty appears to be a general outcome of intellectual impairment. However, performance on tasks of implicit learning reveals quite a different pattern. Generally, individual differences within typical populations on tasks of implicit learning are smaller than those seen on explicit learning tasks (Reber, Walkenfeld, & Hernstadt, 1991), and performance on some implicit learning tasks appears to be relatively unaffected by intellectual impairment (Ellis, Palmer, & Reeves, 1988). For example, in a study testing memory for spatial location (Ellis, Woodley-Zanthos, & Dulaney, 1989) in college students and cognitively impaired individuals, group differences emerged only when IQ fell below 47. The 51 potential savants included in Young's (1995) sample had IQ scores ranging from 50 – 114. If, as this evidence suggests, the majority of savants for whom IQ data are available show impairment in the mild to borderline ranges, if any, it may be that implicit learning mechanisms are unimpaired in savants. Of relevance to this question are findings showing intact implicit memory in participants with autism and Asperger's syndrome (Bowler, Matthews, & Gardiner, 1997; Gardiner, Bowler, & Grice, 2003; Kamio & Toichi, 2000; Renner, Klinger, & Klinger, 2000; Toichi & Kamio, 2001). Given these findings, the development or adaptation of current implicit learning paradigms in order to investigate implicit learning in savants could provide a fruitful focus for future research (see Chapter 4 for more details).

3.4 Summary

In this chapter an introduction to the savant syndrome literature was provided by attempting to draw together a variety of extant experimental findings and theoretical accounts, while also pointing out some of the outstanding issues, such as inconsistencies in defining savant status. Based on this review, it was concluded that savant skills are most closely associated with ASD and/or features associated with this developmental disorder. In evaluating issues relating to intelligence in savants it was concluded that global measures of intelligence, derived from standardised IQ tests, generally fail to provide insight into the savant syndrome. Neuropsychological accounts of ASD provide potentially important insights into information processing in savants. Specific cognitive mechanisms are proposed to be necessary, but alone insufficient, for skill development in savants. So, for example, as proposed here, implicit learning and sensory-perceptual idiosyncrasies in ASD may play an important role in savant skill development, yet they have received little empirical attention.

Chapter 4: Domains of Functioning of Possible Relevance to Savant Syndrome

The following chapter broadly covers three domains, implicit learning (i.e., learning without conscious awareness), inspection time (IT), and perceptual functioning. All three domains will be examined primarily within the context of the extant ASD literature. Furthermore, age- (particularly the child and adolescent years) and IQ-related changes in implicit learning and IT also will be reviewed briefly.

4.1 Implicit Memory and Learning and Their Measurement

Implicit memory and learning have traditionally been conceptualised as the effect of past experiences upon current performance, when one is not intentionally trying to recall the past experience. Definitions may differ in their particulars, but the majority involve the theme of an implicit knowledge base (in theory dissociable from explicit knowledge) developed through nonconscious learning. Implicit learning is one of several important components of this thesis; however, this literature is far too vast for an exhaustive review within the allotted space constraints. The reader is referred to other works (e.g., Lewicki, Hill, & Cryzewska, 1992; Schacter, Chiu, & Ochsner, 1993; Seger, 1994) for more comprehensive coverage of implicit learning and memory in general. It also should be noted that I am seeking to avoid, as much as possible in this thesis, the implicit-explicit learning controversy (see e.g., Shanks & St. John, 1994 for review) and instead remain agnostic on this issue by subscribing to Perruchet and Vinter's (1998) definition, wherein "implicit learning designates an adaptive mode in which children's behaviour becomes sensitive to the structural features of an experienced situation, without the adaptation being due to an intentional exploitation of some pieces of explicit knowledge about these features." Therefore, within this definition, two important characteristics are described, sensitivity to structure in the environment and lack of intentionality in this structural sensitivity.

How are implicit memory and learning measured? Implicit memory has received greater research attention than implicit learning, especially within the developmental literature. Implicit memory abilities are often assessed via repetition priming tasks, that is, tasks in which one is primed to respond a certain way. For example, a participant may be asked to read a long list of words (including, e.g., "table") followed by a non-interfering, filler task. Later, the participant is asked to provide the first word that comes to mind when given a word stem (e.g., ta___), a word fragment (e.g., _ab_e), or a series of words that are presented too briefly to be clearly seen. Implicit memory effects are demonstrated when participants respond to these cues using stimuli from the original word list (i.e., "table" in this example). Other, similar tasks have been developed that assess priming for a variety of stimuli, such as visual patterns, un/familiar objects, and environmental sounds (see Schacter et al., 1993 for review).

One common procedure for measuring implicit learning involves the use of statistical learning tasks. Statistical learning entails detecting structurally related information within continuously presented stimuli. For example, within the domain of language, participants are exposed to streams of speech and asked to segment words; thus, linguistic units are derived based upon tracking patterns of co-occurring sounds within an "artificial grammar". In this case, grammar does not refer to language *per se*, but rather refers to the building blocks or structural units important for creating meaningful sequences of information, whether auditory or visuospatial. Remarkably, these tasks are appropriate for a wide range of ages and functioning levels. For example, infants as young as eight-months-old can successfully complete such tasks (Saffran, Aslin, & Newport, 1996), when properly adapted. Nevertheless, despite its potentially appealing utility, as yet very few research studies have investigated statistical learning in individuals with developmental disabilities. Moreover, statistical learning tasks have face validity when considering anecdotal reports of savant domain learning and the research literature reviewed in Chapter 2 supporting the detail-focussed information processing style of individuals with ASD; statistical learning tasks examine the incidental learning of componential units of information. In other words, these tasks assess passive or implicit learning of relations between discrete elements of information.

Another commonly utilised method for assessing implicit learning is based on a serial reaction time task (Nissen & Bullemer, 1987). There are many variations, but in essence, participants respond as quickly as possible to a target in a series of stimuli by pressing a corresponding button. Unbeknownst to the participants (i.e., without explicit instruction), a predictable and repeating sequence has been shown to them, usually interspersed with random sequence trials. Assessment of implicit learning is ascertained by comparing RT differences within the predictable versus the random sequence trials. Given the ease with which these two common tests of implicit learning can be adapted for a variety of ages and functioning levels, a hybrid task, involving statistical and predictable co-occurrences of visuospatial stimuli responded to via a button press, was developed for the present thesis.

Implicit learning is used to explain how people learn novel and complex information, without the use of effortful and conscious resources. This automatic abstraction of information is undoubtedly a common feature of everyday cognition (early language learning is a primary, albeit somewhat controversial, example; Saffran et al., 1996) and therefore may play an important role in normal functioning. Moreover, its relation to other domains of cognition remains relatively poorly understood, especially during the childhood and adolescent years. Indeed, important theoretical questions that have been little studied include the relationship between implicit learning and age (within the childhood years) as well as its relationship to intelligence/IQ; the second having particular relevance to better understanding how individuals with low measured IQ may exhibit superior functioning in one or more discrete domains.

4.1.1 Invariance in Performance with Age?

By convention, implicit learning is theoretically independent from general age-related changes (Reber, 1993). Evidence exists to support this notion; Saffran and colleagues (1996) demonstrated incidental learning of language properties in a group of eight-month-old infants. Moreover, Lee, Klinger, and Klinger (2000) have shown that performance on implicit learning tasks is equivalent between groups of children and adults. Reber (1993) provided results from two unpublished studies in which two common forms of implicit learning assessment were used. In the first study, a modified version of the standard artificial grammar task was used to test four- to 14-year-olds; results revealed similar performance across this age range. For the second study, preschool-age participants received an adapted version of the serial reaction time task, revealing a significant learning effect similar to that robustly found in the adult literature. Lewicki et al. (1992) also reported an unpublished study with preschoolers (four- and five-year-olds) involving the implicit acquisition of information about co-variation, the colour of a person's clothes and his/her activity level (passive vs. active). Again, performance amongst these children was typical of that seen in the adult literature. Along these same lines, Meulemans, van der Linden, and Perruchet (1998) used a serial reaction time task to test implicit sequence learning in a group of six-year-olds, 10-year-olds, and adults. When accounting for baseline visuomotor speed, age-related effects were not detected. Most recently, Thomas and Nelson (2001) extended this work further by testing implicit learning via serial reaction time in a group of four-year-olds, seven-year-olds, and 10-year-olds. Again, consistent with Meulemans et al. (1998), when baseline visuomotor speed was taken into consideration for between group comparisons, differences in implicit learning did not emerge. In other words, the shape of the serial reaction time curves was similar across the age groups in both the Meulemans et al. (1998) study and in the Thomas and Nelson (2001) study. In a departure from standard methods, Vinter and Perruchet (2000, 2002) used a novel technique termed the neutral parameter procedure, which includes instructions that led participants to focus on components of the task other than those later assessed for unconscious influences. A neutral (in regard to task achievement) behavioural change in a drawing task was induced; during the drawing of various shapes participants had different starting points associated with different shapes. This avoided tainting implicit with explicit learning processes, in order to assess implicit learning in large groups of children, ages four and 10 years, and in adults. Through the use of this novel task, Vinter and Perruchet demonstrated significant implicitly induced changes in drawing behaviour, but no differences in performance across age groups. The results from these studies converge to suggest that indeed implicit learning is age independent and an early developmental phenomenon.

However, despite the above-noted support for invariance of performance on implicit learning tasks across age groups, at least two studies have documented age-related changes in performance. Maybery, Taylor, and O'Brien-Malone (1995) demonstrated differences in performance across two age groups (five- to seven-year-olds and 10- to 12-year-olds) when required to acquire information implicitly about co-variation in the context of an adapted matrix-learning task; location of a picture within a 4 x 4 matrix co-varied with both the colour of the matrix apparatus and the side of approach of the examiner. Performance within the older age group was superior to that of the younger children (who showed chance levels of performance), with the former group more accurately guessing the location of the target picture. A second finding of age-related improvement on an implicit learning task was documented by Thomas et al. (2004). In this fMRI study comparing activation pattern differences between seven- to 11-year-old children and adults in the context of a serial reaction time task, not only did adults outperform children, but they also showed different activation patterns in association with implicit learning performance (particularly in the right medial temporal lobe; activation was greater for the predictable than the random condition for adults, but an opposite activation pattern was observed in children). These two studies, although the exceptions when considering all of the available data, contribute to the ongoing debate regarding the postulated age invariance in implicit learning.

Given the theoretical importance of documenting invariance in age-related implicit learning, a relatively small developmental literature exists to elucidate this issue. Taken together, this small group of studies suggests that implicit learning, even across different methodologies, is likely to be invariant with age. Age differences appear to be influenced more by task constraints (e.g., fine motor demands) than implicit learning ability, though further replication and extension are required.

4.1.2 Implicit Learning and Intelligence

Does implicit learning capacity vary with intellectual level? Reber (1993) suggested that, in theory, implicit learning performance should be invariant with IQ. This issue, which is of considerable theoretical significance, has been addressed in a number of studies, some of which were reviewed in Chapter 3. One method for addressing this question has been to provide a contrast or dissociation of function whereby implicit and explicit memory or learning performance comparisons are made within special groups. So, for example, individuals with intellectual impairment have been shown to obtain lower scores on tests of explicit memory compared to average IQ controls (Carlesimo et al., 1997); however, group differences in implicit memory have been shown to be considerably smaller, if not negligible (Ellis et al., 1988). Corroborating these findings, Atwell, Conners, and Merrill (2003), Vinter and Detable (2003), and Vicari, Bellucci, and Carlesimo (2000), utilising a variety of procedures, have shown that, unlike explicit learning, implicit learning was not impaired in individuals with intellectual impairment. Moreover, individual differences within typical populations on tasks of implicit learning were smaller than those seen on explicit learning tasks (Reber et al., 1991), again indicating independence from intelligence. Extending assessment to the other end of the normal curve of IQ, Fletcher, Maybery, and Bennett (2000) not only assessed implicit learning amongst individuals with intellectual impairment and those with typical development, but also those individuals who had been deemed academically gifted. Unlike the studies mentioned above, they found IQ to be an important indicator of not only explicit, but also implicit learning performance. Despite this exception, the trend in the data indicates that, at least when comparing intellectually impaired to normal IQ individuals, implicit learning is generally independent of intellectual functioning.

As mentioned earlier, this chapter refrains from delving into the controversy surrounding the implicit-explicit distinction in cognition. Nevertheless, choosing an implicit learning task that balanced robust support in the extant literature with minimisation of intervening explicit influences, contributed to the hybrid task developed (and described in Chapter 5). Unfortunately, intervening explicit influences cannot be ruled out in many of the classical learning paradigms (Shanks & St. John, 1994), such as the examples presented above. So, for example, Komatsu, Naito, and Fuke (1996) assessed implicit memory in the form of priming in children, adults, and individuals with intellectual impairments. In the two priming experiments, participants were asked to read a bracketed word in a sentence or to generate a word to its definition. Priming for the words read in the sentence was equivalent among the three groups, but priming effects were substantially greater for the adults in the condition requiring generation of a word to its definition. Results from this study and others similar to it (e.g., Fletcher et al., 2000) were used to argue that perceptual aspects of implicit memory are indeed independent of age and IQ, whereas more conceptual knowledge, even when primed, may vary with age and IQ, possibly reflecting encroachment of explicit knowledge on implicit memory. This example only serves to reiterate why a task with very little conceptual knowledge demand (i.e., identifying four colours) and simple response format (i.e., pressing one of two buttons) was ultimately chosen.

4.1.3 Implicit Memory and Learning in Autism Spectrum Disorders

Is implicit learning affected by the presence of an ASD, whether or not in the context of intellectual impairment? Implicit learning *per se* has not been well addressed within the ASD literature. However, the limited research thus far suggests intact implicit memory in individuals with ASD of average range IQ. Bowler and colleagues (1997) used a word stem repetition-priming task in testing a group of adults with Asperger's syndrome. Results confirmed comparable priming effects for individuals with Asperger's syndrome and for IQ and age matched controls. Similarly, Renner et al. (2000) documented intact implicit memory in a group of high functioning children with autism through the use of a visual-perceptual repetition-priming task involving the very brief presentation of pictures.

Kamio and Toichi (2000) investigated semantic priming (using a task which could not separate implicit from explicit influences) in a group with autism and a well-matched control group across two conditions, a within modality condition (word-word) and an across modality condition (picture-word). Semantic priming was noted for both groups in both conditions; however, within group comparisons revealed that the control group performed comparably across the word-word and picture-word conditions, whereas individuals with autism performed better in the latter condition. Together, these results suggest an advantage for semantic access via nonverbal/pictorial routes versus verbal routes for individuals with autism. This finding is not entirely surprising given the multitude of IQ profile studies conducted in the autism literature that suggest that, at a group level, nonverbal skills are generally superior to verbal skills in classic autism (e.g., Goldstein, Beers, Siegel, & Minshew, 2001; Rumsey, 1992). This route, as the preferred mode of learning, is an important component of a number of widely used and praised intervention techniques (e.g., PECS: Bondy & Frost, 1994; and TEACCH: Schopler et al., 1995).

In a complementary study, Toichi and Kamio (2001) used a word fragment semantic priming task to examine similarities and differences between a group of high functioning individuals with autism and a matched control group. Again, semantic priming effects were similar for both groups suggesting intact conceptual relationships at the single word level, corroborating work reviewed in Chapter 2.

In the only study to use a statistical learning methodology, Klinger, Lee, Bush, Klinger, and Crump (2001) documented intact artificial grammar learning in a group of children with high functioning autism. Based on the hypothesis that an implicit learning deficit may contribute to social and language difficulties observed in ASD, these researchers had predicted impaired implicit learning in ASD. Performance on the artificial grammar learning task was not impaired for children with high functioning autism; however, unlike TD controls, performance on the artificial grammar learning task was related to explicit learning for children with ASD. In this sense, children with ASD may be using explicit processes to learn the sequence, counter to the usual implicit processing strategy, or it may be that individuals with ASD may be more reliant on implicit learning processes than other children, even in usually explicit tasks.

Thus far, there has been one exception to findings of intact implicit learning in autism. Mostofsky, Goldberg, Landa, and Denckla (2000), using a serial reaction time task, found a deficit in implicit learning for children with autism as compared to matched controls. Individuals with autism were not only slower in general on the task, but they did not show the characteristic decline in RT associated with learning. However, the version of the serial reaction time task used in this study blocked separately random and predictable sequences, instead of allowing them to be interspersed with one another. The blocking of these conditions has two disadvantages: it is more likely to result in fatigue effects and it is more likely to bring an implicitly predictable sequence to explicit awareness. Indeed, the TD individuals in this study responded in a way consistent with explicit awareness of the predictable sequence (Willingham, Salidis, & Gabrieli, 2002).

In spite of this exception, going with the trend in findings; what is the implication of intact (and perhaps surprisingly good, given developmental level) implicit learning in ASD, as documented in the studies above? Speculatively, these skills may be tied to the purported ease with which savants naturally learn within their interest area. Interestingly, Lucci and colleagues (1988) noted that Paul, a musical savant, demonstrated excellent incidental learning of digit-symbol pairs (where there was no explicit instruction to retain this pair-wise information for later recall) from the Coding subtest of the Wechsler Intelligence Scales for Children-Revised edition. He recalled perfectly all nine pairs, and remarkably, this occurred despite his poor performance on the task itself (as measured by number completed), and his limited exposure (90 seconds) to the information. Similarly, although not investigating implicit learning *per se*, Pring and Hermelin (2002) devised an intriguing experiment in which a calendar savant and two control subjects (including a mathematics professor) were asked to complete an associative learning task whereby they learnt novel digit-symbol pairs. The savant, unlike the control participants, was able to quickly and efficiently learn the new associations (even after the associations/rules were altered) without any errors on first testing of rule learning. These are not the first allusions to the potential importance of implicit learning to savant skill development (e.g., Hermelin, 2001; Spitz, 1995; Treffert, 1989); however, these are some of the only data providing (indirect) support for a hypothesised superiority.

The present thesis aims to extend this research by utilising a visuospatial implicit learning task with a hybrid statistical learning presentation and a serial reaction time response format. This task was chosen because it was anticipated to be accessible to individuals of varying ages and levels of functioning. Based on the populations of interest here, the statistical learning paradigm may be more appropriate than repetition-priming tests because of its reliance on associative and rule-based learning of relatively simple information, areas of relative strength in ASD (Klinger & Dawson, 2001; Minshew & Goldstein, 2001). Moreover, unlike repetition priming tasks that rely on past experiences, statistical learning tasks assess a participant's ability to extract structure from sequential stimuli, a potentially powerful research design when applied to savants. Finally, extending work by Klinger et al. (2001), this type of task can be used with not only high functioning individuals with ASD, but also with low functioning individuals as well.

Based on the above reviewed literature, it is predicted that children with ASD will demonstrate unimpaired performance while savants will demonstrate superior performance on tests of implicit learning when compared to age and IQ matched control participants. Consistent with previous findings in the implicit learning literature, performance on implicit learning tasks is predicted to be independent of intellectual functioning and age across all groups.

4.2 Inspection Time and Savant Skills

Much of the early interest in the savant syndrome surrounded its relevance to intelligence theory (see Chapter 3). Although very few intelligence theories account for savant skills in their formulations, there are a few notable exceptions. Outstanding amongst these is Anderson's theory of the minimal cognitive architecture at the heart of intelligence and cognitive development (Anderson, 2001). Briefly, this theory posits that knowledge, as assessed by traditional IQ measures, is acquired via two main routes, thinking and dedicated processing systems known as modules. One significant constraint on thought is the speed of a basic processing mechanism, which in turn determines individual differences in general intelligence. Moreover, speed of processing constitutes the unchanging, innate basis of these individual differences. The idea that a basic speed of processing mechanism contributes to or underlies aspects of intellectual functioning is not new and is in fact a major component of a number of theorists' views of general intelligence (e.g., Eysenck, 1988; Jensen, 1982; Nettelbeck, 1987). Evidence to support the relationship between a basic processing mechanism and intellectual functioning exists mainly in the form of correlations between measures of general intelligence and IT, now the predominant way to assess speed of information processing. As defined by Anderson and Miller (1998), IT is "the stimulus exposure duration required by a subject to make a simple perceptual judgement, for example, the relative length of two lines". So, IT describes the minimum stimulus exposure at which a person consistently and accurately discriminates a stimulus feature. Exposure time of the stimulus is therefore varied in order to determine optimal performance. In this way, IT avoids difficulties inherent to RT studies, such as motoric and "thinking time" confounds when responding. These are especially apparent when the participant is unsure how to respond, which may result in a "speed/accuracy trade-off". Indeed, IT may inherently tap neural processing speed, possibly one of the biological underpinnings of intelligence. Based on meta-analytic studies of TD adults and children, the correlation between IT and intelligence seems to hover around -.50 (Grudnik & Kranzler, 2001; Kranzler & Jensen, 1989; Nettelbeck, 1987).

In Anderson's model, the second significant method of knowledge acquisition occurs via modular processing. In theory, these dedicated processing mechanisms provide complex representations of the world that cannot be provided by the more general, central processes of thought, and are hence independent of them. In practice, this then implies that modular processing should not be related to IT, the underlying mechanism of general intelligence. Both notions of processing speed and modular processing have particular relevance to understanding savant skills, considering how commonly descriptions include ease and speed with which tasks are completed by savants and the domain specificity of their skill (i.e., independence of the skill from intellectual functioning or skills in other domains). When testing calendar calculating savants, Hermelin and O'Connor (1983) found that their RT on most tasks was commensurate with their relatively low IQ, but when asked calendar questions, their RT was far better than predicted by their IQ. It is possible that either processing speed (as measured by IT) is intact or superior in savants or that savant skills are acquired via a modular route independent of processing speed and IQ.

In the one group study of IT and autism to date, IT amongst individuals with autism (Scheuffgen, Happé, Anderson, & Frith, 2000) was compared to that obtained in a group of IQ matched controls and in relation to expectations based on their own IQ scores. Interestingly, IT in autism was much better than expected, based upon the group's measured IQ; IT in the autism group was equal to that in a TD group with IQ scores 20 points higher on average and significantly better than that of an IQ matched MLD group. Therefore, this possible underpinning of intelligence was intact (or better) amongst individuals with autism, indicating that some other aspect(s) of cognition contributing to IQ is responsible for the depressed aspects of the IQ profile frequently observed in autism.

Anderson et al. (1998) showed that the IT of a savant prime number calculator with autism was consistent with that of typical university undergraduates, but inconsistent with his own low IQ. The findings from this study are consistent with the aforementioned study (Scheuffgen et al., 2000) in that people with autism demonstrate an IT commensurate with or superior to their own IQ. Therefore, it may be that superior processing speed is necessary for the development of some savant skills.

The present investigation attempts to extend the research in this area by 1) replicating the Scheuffgen et al. (2000) findings of relatively good IT compared to measured IQ in autism, and 2) extending the findings from Anderson et al. (1998) to measure IT in a number of savants. It is predicted that: 1) individuals with autism will display an IT better than predicted by their IQ, 2) correlations between IT and IQ will be significant for the TD and MLD children, not for the ASD children, and 3) savants with ASD will demonstrate a significantly faster IT than that shown in comparison groups.

4.3 Perception and Sensation

The general consensus within the field is that social communicative difficulties are the pathognomonic sign of ASD and its core deficit (see Chapter 1). However, it is clear from anecdotal evidence, many older classical studies (e.g., Hermelin & O'Connor, 1970; Rimland, 1964), and clinical experience that social deficits do not "tell the whole story" of the day-to-day experiences of individuals living with ASD. For example, both the lay and academic ASD literatures are littered with examples of abnormal responses to sensory stimuli, whether exemplified by over- or under-arousal, odd visual fixations, or preoccupations with certain sounds, smells, or tastes. Temple Grandin, perhaps the most famous person with ASD, and Associate Professor of Animal Science at Colorado State University, describes the soothing effects of her "squeeze machine", which effectively limited sensory input during periods of overarousal (Grandin & Scariano, 1986). In her own words: "High-pitched sounds, sudden movements, really attract my attention; I can't shut that out. I have this anxiety all the time. Loud sounds hurt my ears; I'm hyper-vigilant, hyper-sensitive" (www.grandin.com). It is tempting to dismiss these odd reactions to sensory stimuli as superfluous to better understanding ASD, especially when one considers that these sensory-perceptual oddities are also observed in idiopathic intellectual impairment (e.g., Fox & Oross, 1990; Shinkfield, Sparrow, & Day, 1997). However, the example above of an individual with ASD who has obtained a doctoral degree and subsequently a professorship reiterates that these idiosyncratic sensory-perceptual experiences are not limited to the lowest functioning subset of individuals with ASD (indicating potential independence from IQ). Indeed, many of the classic accounts of autism consider this to be an integral part of the disorder (e.g., Hermelin & O'Connor, 1970; Rimland, 1964). Before delving into the evidence supporting or refuting this contention, some context will be given through a brief and general description of perception. This will then be followed by a summary of the small body of literature devoted to perceptual and sensory functioning within ASD, concluding with a review of the main theories given to explain perceptual peculiarities observed in ASD.

Perception is often defined as the process of interpreting and understanding sensory information; in other words, the beginning of information processing. Perception requires attention and awareness. If sensation was identical to perception, it would follow that we should be aware of each of the countless sensations that bombard us during each moment of consciousness. Because we are not aware of every sensation, indicating that sensation is not identical to perception, "vision" and "visual perception" are two different phenomena.

Perception can then be thought of as one of the first stages when the brain processes external information for interpretation, and it forms one of the building blocks of higher-level cognition. Despite its status as one of the first and lowest levels of cognition, perception is nevertheless a complex process. Perception encompasses how we encode, recognise, and categorise the world. Indeed, perception may describe the processes allowing organisation of the external world as encoded by our senses (e.g., Aslin & Smith, 1988; Bertenthal, 1996). Like a reflex, it may be conceptualised as a computational mechanism that is both efficient and low-level. Similarly, this mechanism is efficient because it "knows" how to encode properties of the world via rules and representations. It is also low-level because in large part it operates automatically; requiring no intervention by higher-level cognitive processes.

Importantly, from a neuropsychological perspective, aspects of (visual) perception are indeed modular so that different subsystems (e.g., motion, shape from shading, stereopsis, and surface texture) may work in parallel (possibly independently, depending on the circumstances) on different types of representations (Kolers, 1983). Despite this modularity, perception is not completely independent of higher-level cognition/thought. For example, in a previously mentioned study, Ropar and Mitchell (2002) examined the perception of actual versus viewed shape constancy in a sample of TD children and adults. Prior knowledge of a circle's actual as opposed to viewed shape influenced perceptual judgements of that shape. However, higher-level cognition or thought cannot penetrate our perceptual systems entirely. For example, even if you know that a pair of lines is the same length, you may not perceive them as being the same length in the case of the famous Müller-Lyer illusion.

Two important psychophysical/perceptual phenomena are especially relevant to the study of ASD; detection and discrimination. Detection involves the absolute threshold or the boundary between detectable and undetectable input. For example, how loud does a phone ring have to be for one to hear it in a quiet room? Discrimination, on the other hand, involves the amount by which a stimulus must be changed in order to produce a noticeable difference. For example, how different in pitch do the rings of a pair of phones need to be in order for one to tell the difference? Detection would therefore be relevant to issues of hyper- and hypo-sensitivity to stimuli, while discrimination may have particular relevance to the notion of heightened featural processing or WCC in ASD (see Chapter 2).

4.3.1 Sensory Functioning in Autism

Despite claims that abnormalities in sensory functioning are not primary to the aetiology of autism, until recently, very little empirical work actually has been conducted in this area. One aspect of sensory functioning often mentioned in relation to ASD is modulation of responses to sensory stimuli, resulting in either over- or under-arousal or some combination of the two to various forms of sensory input. So, for example, hyper-reactive children tend to have low sensory thresholds, resulting in more frequent sympathetic nervous system responses, such as increased heart rate and blood pressure (Miller & McIntosh, 1998). This could then be logically linked to the increased likelihood of anxiety-related conditions often involving fear related to certain sensory stimulation in ASD. Moreover, in an attempt to cope with or avoid these stimuli, individuals with ASD may adopt strict routines, compulsions, and stereotypic patterns of behaviour. However, not all reactions are negative, as children with ASD may find certain stimulation, such as spinning wheels or tops (Kanner, 1943), both consoling and soothing. Indeed, repetitive behaviour seems to modulate arousal both up and down (e.g., Guess & Carr, 1991; Runco, Charlop, & Schreibman, 1986).

Until recently, very little research had addressed sensory abnormalities in ASD (O'Neill & Jones, 1997), aside from the relatively small auditory integration and occupational therapy literatures, which tended to employ rather small samples and often failed to employ appropriate control groups, matched for IQ or mental age, for example. However, recent attention has been given to this area and has overcome shortcomings of the older literature. For example, Rogers, Hepburn, and Wehner (2003) utilising the Short Sensory Profile across four participant groups matched on mental age, found that young children with autism or fragile X syndrome had significantly more symptom endorsements than either a group of TD children or a group of children with idiopathic intellectual impairments. Moreover, children with autism were more abnormal in their responses to taste and smell than all other groups. IQ was not related to Short Sensory Profile ratings for any of the groups, but adaptive functioning was, highlighting the potential relevance of sensory difficulties to everyday functioning. Similarly, in a recent study, Baranek, David, Poe, Stone, and Watson (2006) found that amongst 56 children with autism (strictly defined), 50% showed a profile of only hypo- or hyper-responsiveness to sensory stimuli (using a questionnaire developed by their lab, the Sensory Experiences Questionnaire), while the other 50% showed both patterns across various sensory domains. Moreover, across the entire study sample (258 children, mean age 34 months) there was a decline in sensory symptoms with an increase in mental age. A more detailed analysis comparing types of sensory symptoms endorsed across all four groups (TD, autism, ASD, and other developmental disorder) showed that items indicating hypo-responsiveness were more often endorsed when rating children with autism than all other groups. On the other hand, hyper-responsiveness seemed to co-occur with intellectual impairment, rather than autism *per se*. In a study of 199 individuals with an ASD, a Swedish group (Rosenhall, Nordin, Sandstrom, Ahlsen, & Gillberg, 1999) found higher than expected prevalence rates of profound hearing loss (3.5%), which was unrelated to IQ level. Moreover, consistent with anecdotal reports, hyperacusis was quite common (18%), similar to recent reports of individuals with William's syndrome (Levitin, Cole, Lincoln, & Bellugi, 2005).

Returning to the issue of effects of sensory hyper- and/or hypo-sensitivity, Hirstein, Iversen, and Ramachandran (2001) assessed sympathetic (i.e., "fight or flight") reactions of the autonomic nervous system for individuals with autism as they completed everyday activities; they found that individuals with autism used self-stimulatory behaviour to calm the hyper-responsive nervous system. For those who were hypo-responsive, only self-injurious behaviour activated sympathetic responses from the autonomic nervous system.

Perhaps most relevant to a greater understanding of special skills and to linking WCC to sensory functioning, children who tend to be hyper-reactive have been suggested to be overly focused on detailed information in stimuli (Kinsbourne, 1987). Hyporeactive individuals, on the other hand, require a great deal of stimulation before registration of the stimulus occurs. However, when a type of stimulation is found that provides any sort of positive feedback, the individual with autism often seeks it out repeatedly, to the exclusion of other aspects of the environment. Indeed, individuals may have a mixed pattern of these two types of sensory dysfunction, such as tactile or auditory defensiveness, plus demonstrating proprioceptive or vestibular hyposensitivity (e.g., Ermer & Dunn, 1998). There are even reports of within-domain mixed patterns so that an individual can be hyposensitive to high frequencies of sound (e.g., sirens), but hypersensitive to low frequencies of sound (e.g., a running generator). Therefore, the profile heterogeneity of sensory abnormalities across individuals impedes researchers' ability to demonstrate their significance on a group level. So, when investigators rely on measures of central tendency (e.g., the mean), for example, the hyposensitive individuals' scores may cancel out those of the hypersensitive individuals. Therefore, in this thesis, a sensory profile was obtained whenever possible in order to examine individual patterns of sensory functioning.

4.3.2 Perceptual Functioning in Autism

Perceptual issues in ASD have been long debated, but received a great deal more attention during the early days of the disorder than is presently the case. In fact, the last two decades have seen a sea change in research focus from lower-level cognitive processes, such as perception, to higher-level skills such as social cognition and executive functions. Nevertheless, a swing in attitude and perspective suggests that researchers should return to examining perceptual functioning in ASD in order to more clearly elucidate this group of disorders (see Chapter 2). Most investigators in the ASD field agree that perceptual abnormalities do not constitute (an aspect of) the primary deficit(s) of the disorder, because these difficulties are not universal (based on the limited studies to date), are not the first noticeable sign of impairment during early development, and are not specific to ASD. However, the importance of these deficits has gained greater recognition as, for example, more data reveal sensory-perceptual peculiarities in the early development of children with ASD (e.g., Baranek, 1999).

As earlier mentioned, studies of perceptual functioning in ASD have also traditionally been small and lacking rigor in terms of controlling for IQ and other important cognitive variables. Perhaps more intriguingly, there have been even fewer examinations of the potential benefits of these perceptual idiosyncrasies. WCC theory predicts enhanced perceptual discrimination due to favoured featural processing in ASD. Indeed, Kanner (1951) documented a number of instances of good visuospatial and auditory discrimination in his original series of case studies involving children with autism (e.g., noticing when items on a bookshelf were out of order or when words in a story were pronounced differently). More recently, studies into visual perception have shown that people with autism, in the context of a visual search paradigm, have increased sensitivity to unique features in visual stimuli (Plaisted et al., 1998) resulting in enhanced visual discrimination (O'Riordan & Plaisted, 2001).

Similarly, but in the auditory domain, excellent pitch discrimination skills in musically naïve individuals with autism have been demonstrated by Heaton and colleagues (1998) as well as Bonnel et al. (2003). Recent work has extended these findings by showing that people with autism preferentially perceive music in a piecemeal fashion when the task at hand is reliant on long-term pitch memory; however, individuals with autism are just as likely as controls to succumb to the gestalt properties of music when this is not the case (Heaton, 2003). Despite performance differences favouring individuals with ASD, Tecchio et al. (2003) found that low functioning individuals with autism demonstrate abnormalities at preconscious stages of cortical processing during an auditory discrimination task (i.e., an auditory oddball paradigm). However, Ceponiene et al. (2003), using event-related potentials of simple tones, complex tones, and vowel sounds in three separate oddball paradigms, found that abnormalities in orienting to sound may be speech-sound specific. Gervais et al. (2004) demonstrated that cortical network activations to voices in fMRI were abnormal for individuals with autism, unlike activation patterns for non-speech sounds. Plaisted, Saksida, Alcantara, and Weissblatt (2003) found the width of auditory filters to be abnormally broad in autism in contrast to their predictions of superior discrimination. Complementing this study, Alcantara, Weisblatt, Moore, and Bolton (2004) demonstrated that individuals with autism had more difficulty processing speech against a background of noise than did control participants. The weight of evidence in this field so far indicates that individuals with ASD have particular difficulty with speech-related auditory processing.

Importantly, in her comprehensive review of the relevant literature from Kanner's original studies through the 1970s, Prior (1979) noted that indeed, some children with autism struggle with perceptual tasks, but that other, select individuals perform better than TD individuals. Frith and Baron-Cohen (1987), in their review of the literature concurred with Prior in concluding that the studies did not support the contention of consistent and fundamental low-level perceptual difficulties for individuals with autism. However, the present author would contend that the more recent evidence, including that cited in this chapter and Chapter 2 covering WCC, argues for a re-evaluation of this position. So, for example, although Frith and Baron-Cohen (1987) have argued that, based on commonly used sensorimotor tests, children with autism do indeed perceive constancies of size, shape, and so forth (Sigman & Ungerer, 1981) in a typical fashion, recent data from Ropar and Mitchell (2002) may in fact contradict these findings. They found that people with autism were less affected by prior knowledge (saying it is a circle) than matched controls, in determining the constancy of a shape, indicating a lack of top-down modulation on perception amongst individuals with autism. This finding is interesting in light of results obtained by Phillips, Chapman, and Berry (2004), in which TD males were also less affected by prior knowledge in their perceptual judgements than were TD females. A recent surge in interest in perceptual functioning amongst people with ASD, resulting in more tightly controlled experiments and in-depth investigations, has indicated a number of perceptual-level idiosyncrasies, which have been highlighted in previous chapters (see Chapters 2 and 3). Recent perception-related theories (e.g., WCC, EPF, and extreme male brain theory) accompanying these new studies have been discussed in previous chapters (see Chapters 2 and 3).

4.3.3 Theories of Perceptual Difficulties in Autism

Because of the above noted empirically demonstrated and anecdotally reported perceptual peculiarities, various researchers have proposed a number of theories to account for these behaviours at various levels. One of the first, the Sensory Dominance hypothesis (Goldfarb, 1956; Schopler, 1965), stated that children with autism over-utilise proximal receptors (i.e., touch, taste, and smell), which was thought, at the time, to reflect a trend within early stages of typical development. This was contrasted with underutilisation of distal receptors (vision and audition) by these children, which constituted a more complex and therefore later stage of typical development. The hypothesis focussed on why children with autism struggled with mastering use of these distal receptors and were therefore socially isolated, while they seemed to take interest in and were comforted by idiosyncratic stimulation derived from the proximal receptors. Unfortunately, data supported neither the proposed pattern of usage of these receptors in typical development, nor their atypicalities in the context of autism (Hermelin & O'Connor, 1964; O'Connor & Hermelin, 1965). Future research and theorising then attempted to build and improve on this first attempt.

Perceptual Inconstancy, built on a model of brainstem dysfunction and coined by Ornitz and Ritvo (1968), was proposed to account for the unusual motility patterns and odd stimulation-seeking behaviours commonly observed in autism. According to their theory, abnormal states of arousal in autism derived from brainstem dysfunction and accounted for the resulting fluctuating states of overexcitation and overinhibition, which varied an individual's experience with the same stimulus. The central premise held that individuals with autism demonstrated an "inability to regulate sensory input". However, this account suffered for lack of universality and specificity: these brainstem mediated functions were later found to be variably expressed amongst individuals with ASD, largely related to their IQ and functioning level (e.g., Gabriels, Cuccaro, Hill, Ivers, & Goldson, 2005; Poustka & Lisch, 1993), therefore, lacking universality. Not all children with ASD had this impairment, and these abnormalities could be found in other children with developmental disabilities (Guess & Carr, 1991).

The Stimulus Overselectivity hypothesis (Lovaas, Schreibman, Koegel, & Rehm, 1971) attempted to explain why children with autism respond to only one of many possible cues or to only a part of a cue within the environment. Unfortunately, it was found that the phenomenon of overselectivity is not autism specific, but rather is found often in the context of intellectual impairment (e.g., Anderson & Rincover, 1982; Gersten, 1983; Koegel & Lovaas, 1978). Various mechanisms have since been postulated to account for overselectivity. For example, Kinsbourne (1987) as well as Dawson and Lewy (1989) put forward the idea that these difficulties derive from overactivation of arousal mechanisms operating in the brainstem, similar to Ritvo et al.'s account mentioned above. It then follows that the narrowed attentional focus, motor stereotypies, and social isolation are an adaptive mechanism resulting from the individual's attempt to de-arouse. Courchesne et al. (1994) have proposed a disturbance of neocerbellar circuitry, controlling coordination of the rapid shifting of selective attention, as the mechanism responsible for overselectivity, as well as other symptoms of autism. It has therefore proven an informative and productive theory despite findings of non-specificity to autism.

4.3.4 Relevance of Perceptual Findings to Savant Skills

Although perception in the traditional modalities (i.e., visual, auditory, tactile, and olfactory) has not been fully explored, other perceptual skills have been even more neglected in the ASD literature. For example, there is a significant literature on time perception both within the context of typical development and within the ADHD literature (Barkley, Edwards, Laneri, Fletcher, & Metevia, 2001; Smith, Taylor, Rogers, Newman, & Rubia, 2002). Despite the presence of this literature, autism has been largely, if not completely, ignored in this context. Weighing the additional evidence of examples in the extant literature of savants with ASD who have a perfect appreciation of time passage without reference to a clock (Treffert & Wallace, 2002), it begs the question as to whether individuals with ASD are particularly good or in tune with their internal clocks, or if they vary in their performance on time perception tasks in a similar manner to TD controls (e.g., Block, Zakay, & Hancock, 1999). Moreover, timing behaviour is important for a number of domains, including musical expertise and calculation, two frequently expressed savant skills (Miller, 1989; Heavey, 2003). Therefore, time perception is one area in this domain that may relate to savant skill development.

The ability to make duration judgements presumably relies upon one or a combination of the following processes: 1) a biological internal clock, 2) basal metabolic rate, 3) translation of objective to subjective units, 4) memory, 5) attentional resources, and 6) delay of response/inhibitory control (Block et al., 1999). One theory, Zakay and Block's (1996) attentional-gate model, suggests that both physiological and cognitive components play significant roles in time perception so that arousal level influences the rate of the internal clock and an attentional gate determines the amount of temporal information that reaches memory store. Given the postulations surrounding ASD as a disorder of arousal regulation (e.g., Dawson & Lewy, 1989), and the robust documentation of attentional abnormalities exhibited by individuals with ASD (Belmonte & Yurgelun-Todd, 2003; Courchesne et al., 1994; Waterhouse, Fein, & Modahl, 1996), it is perhaps surprising that very little research has been conducted on time perception in ASD. One small study (Szelag, Kowalska, Galkowski, & Poppel, 2004) of seven high functioning individuals with autism, and seven sex and age matched controls, demonstrated a deficit in temporal processing in autism. However, the experimental task required participants to reproduce units of time no longer than up to two or three seconds in duration. Subjective duration judgements of greater magnitude are potentially more relevant to the demonstration of excellent appreciation of time passage as described in previous anecdotal reports.

In an attempt to address the gap in our knowledge, this thesis examines duration judgement abilities in all participant groups (i.e., individuals with ASD, controls matched on age and IQ, and TD children), because, in addition to effects from ASD, it is also unclear what effect, if any, intellectual impairment has on these skills. In order to reflect anecdotal reports of this ability and represent naturalistic demands, such as the classroom and home settings, time perception will be assessed at a macro level, that is, on the order of several seconds up to nearly a minute in duration. A great deal of this literature has concentrated on timing at the millisecond level, but this is not the level at which savant capabilities have been expressed. Time perception can be broken down into time estimation, time production, and time reproduction. In one type of time estimation task, a participant is asked to estimate the length of a time passage that s/he observes. During a time production task, a participant is asked to produce a designated time passage. And finally, time reproduction requires the reproduction of a demonstrated time window. Because the time reproduction task relies heavily on good rote memory, a strength in ASD (e.g., Toichi & Kamio, 2002), and does not require recoding, individuals with ASD were predicted to perform better than matched controls on this task. On tasks of time estimation and time production, ASD performance was expected to equal that of matched controls.

4.4 Summary

The weight of evidence to date indicates intact implicit cognitive processes in ASD, though data are limited. Given anecdotal reports of implicit-like learning in savants and their inability to report "how they do it", the present thesis investigates further implicit learning (using a novel and basic task) amongst both nonsavant and savant individuals with ASD. Discrepantly high IT, given IQ-based expectations, has been documented in ASD, and two savants with ASD and MLD. The present study examines mental processing speed, using a well-validated task, amongst normal IQ individuals with ASD (with or without savant skills) in order to determine whether IT predicts savant-like skill (instead of IQ) in the context of ASD. Perceptual functioning in ASD is idiosyncratic, perhaps contributing to cognitive strengths. Based on the findings noted above and from Chapter 2, this thesis examines (in addition to visual perception, as relevant to WCC) time perception, because it has not been systematically studied in ASD, savants, or individuals with intellectual impairment and because of anecdotal reports of perfect appreciation for time passage in at least one case (Treffert & Wallace, 2002). A subset of individuals with ASD also exhibits sensory difficulties, yet the relationship between these impairments and savant skills remains unclear. Therefore, sensory functioning was assessed whenever possible in order to ascertain individual profiles of sensory preferences and experiences.

Chapter 5: Group Study Design and Methodology

As previously outlined in Chapters 2, 3, and 4, various cognitive mechanisms were posited to contribute to the overrepresentation of savant skills in people with ASD. In order to ascertain whether these domains of functioning are indeed intact and/or superior in people with ASD, a group of children and adolescents with ASD as well as a group of controls group matched for sex, age, and IQ were recruited from regular and special schools. Moreover, a group of TD children, from whom some of the matched controls were chosen, were recruited in order to examine, gender, age, and IQ effects on the domains of interest. The aim of this chapter is to describe the participants, procedure, and tasks utilised in the group study portion of this thesis.

5.1 Participants and General Procedure

Twenty-eight school-age (9-18 years) children with ASD took part in the investigation (see Table 5-1 for age, gender, and estimated FSIQ breakdown). Exclusion criteria for the ASD group included any known co-morbid medical conditions, such as fragile X syndrome, other genetic disorder, or neurological disorder (e.g., Tourette's syndrome) which may affect cognitive functioning. Inclusion criteria were deliberately broad due to the frequent omission of low functioning children from research investigations and because of the relevance that individuals of low intellectual levels have for understanding savant skills. The diagnosis of an ASD, based upon DSM-IV criteria (APA, 1994), had been given in every case, by an independent clinician, as recorded in clinical notes. Participants with ASD were recruited from two specialised residential schools, one for children and adolescents with Asperger's syndrome in the southwest of England and another for children with MLD and/or ASD in the southeast of England. Additionally, from discussion with these pupils' teachers, it was determined that none of these individuals exhibited savant skills at a prodigious level.

Twenty-eight members of the control group, composed of TD children (n=21) and children with MLD (n=7), were group matched to children in the ASD group based upon estimated FSIQ, age, and sex (see Table 5-1 for details). Similar to the ASD group above, exclusion criteria for the children with MLD consisted of known genetic and neurological disorders and FSIQ < 50, as well as any history or documentation of autistic traits. In addition, to validate the utility of the experimental measures across wide age and developmental levels in the context of typical development and to examine research questions co-varying the effects of age and IQ, a broader group (inclusive of 21 members of the control group) of TD children (n=64), composed of 38 boys and 26 girls, was used (see Table 5-2 for details). Though the chronological age of the TD children was lower than that for the groups of children with ASD and matched controls (see Tables 5-1 and 5-2), the three groups were matched approximately in terms of mental age (see Figure 5-1). MLD participants were recruited from a specialised residential school in the southeast of England while TD children were recruited from primary and secondary schools in the London area.

Table 5–1. Characteristics of the ASD and Matched Control Groups: Mean (SD).

Variable	ASD (n=28)	Matched Controls (n=28)	Statistic	*p*
Age	14.29 (2.00)	14.08 (2.23)	F = 0.14	.71
Gender (% male)	96%	89%	Fisher's Exact Test	.61
FSIQ Estimate[1]	93.21 (22.83)	95.04 (21.19)	F = 0.10	.76

[1] Standard Scores

Table 5–2. Characteristics of the Group of TD Children: Mean (SD).

Variable	All TD Children (n=64)	Males (n=38)	Females (n=26)	Statistic	*p*
Age	11.77 (2.32)	12.01 (2.19)	11.43 (2.50)	F = 0.97	.33
FSIQ Estimate[1]	107.75 (11.80)	108.21 (12.76)	107.08 (10.44)	F = 0.14	.71

[1] Standard Scores

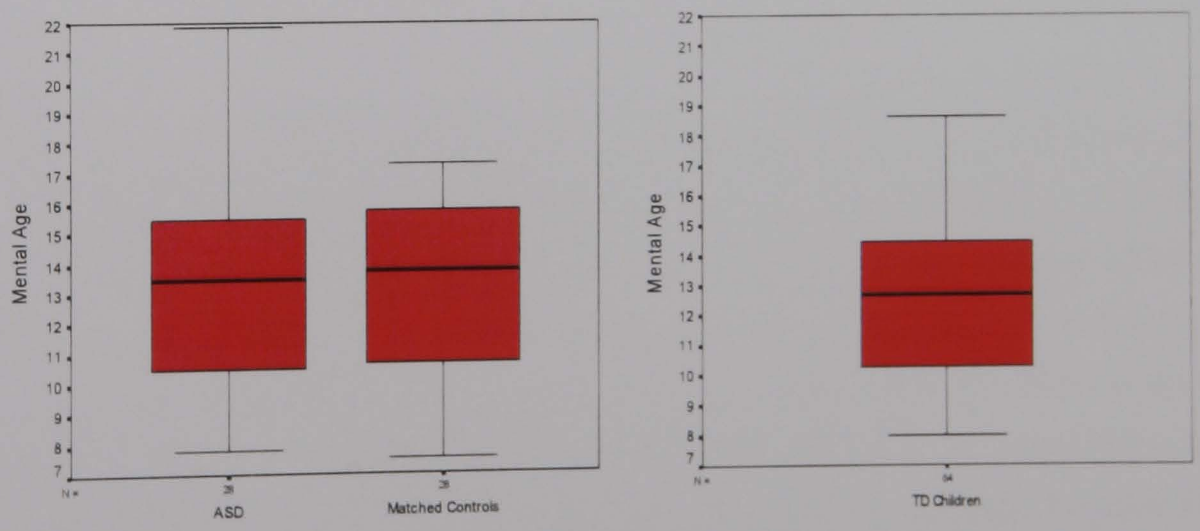


Figure 5–1. Box Plots of Mental Age Distributions for Children with ASD, Matched Controls, and TD Children.

All participants were seen individually in a quiet place in a school, meeting, or clinic room. Where appropriate, all stimuli were presented on the same computer, which was equipped with a child-friendly touch screen (used only for a portion of tasks) on a 12 inch Video Graphics Array monochrome monitor (brightness held constant across testing sessions). The other tasks were paper and pencil format. In order to control for possible reading comprehension differences/difficulties, instructions for tasks were orally presented to each participant regardless of whether instructions were also presented visually. Participants were seen two or three times for periods lasting from 30 minutes to one hour, depending on the school's schedule and the individual's tolerance for testing. Total testing time varied from 90 to 120 minutes per participant. In addition to standard clinical measures, a test battery assessing four domains (implicit learning, central coherence, time perception, and processing speed) was administered to all participants.

The experimental test battery was piloted for feasibility, length and appropriateness on small groups (2-3/group) of children with ASD, children with MLD, and TD children. The clinical and experimental measures are described below.

5.2 Clinical Measures:

5.2.1 Wechsler Intelligence Scales for Children-Third Edition, UK Version (WISC-III-UK: Golombok & Rust, 1992)

The Wechsler Scales are the most widely utilised and psychometrically sound measures of intelligence currently available. Short forms of the Wechsler Scales, particularly those involving the two most robust subtests, Vocabulary and Block Design, have been shown to reliably predict an individual's FSIQ (Sattler, 1992). Recent work suggests that short forms are also valid in predicting FSIQ, even when utilised with individuals on the autism spectrum (Minshew, Turner, & Goldstein, 2005). Recent work suggests that short forms (including two subtest forms) are also valid in predicting FSIQ, even when utilised with individuals on the autism spectrum (Minshew, Turner, & Goldstein, 2005). Due to time constraints and in order to concentrate as much of the testing sessions as possible on experimental tasks, a two subtest short form (i.e., Vocabulary and Block Design) of the WISC-III-UK was administered to all participants (see Appendix A for the subtest scores and IQ estimates for each of the ASD and matched control participants), instead of, for example, the four subtest Wechsler Abbreviated Scales of Intelligence. Vocabulary and Block Design have been shown to load most highly onto the general intelligence factor (Cyr & Brooker, 1984).

5.3 Experimental Measures:

5.3.1 Implicit Learning

This task combined two paradigms: a traditional serial reaction time task (in this case a simple repeating sequence paradigm) and statistical learning. A previously utilised visuospatial statistical learning task (Kirkham, Slemmer, & Johnson, 2002) for infants and toddlers was adapted to allow for greater variation in performance and to avoid floor and ceiling effects as may be expected with the wide age and ability range of the participants seen here. The shape sequences were presented in the centre of the computer display using Superlab Pro® software. Participants were first given the general instructions to press the green mouse button (left click) when they saw a green shape and to press the yellow mouse button (right click) when they saw a yellow shape. If any other coloured shape appeared, they were told to refrain from pressing a mouse button. Therefore, there were only two possible responses. Any one of four differently coloured shapes (i.e., blue triangle, pink square, green circle, or yellow cross) could appear on the computer display. For administration of the task, the first step taken was to insure that each participant could accurately discriminate and point to any one of the four named colours. Then, a short practice session of 20 shapes was utilised to familiarise the participant with the testing procedure. Within the structured condition there were a series of predictable shape co-occurrences. The appearance of the pink square predicted 100% of the time that the following shape would be the green circle. The chance of any of the four possible shapes appearing was equated (i.e., 25% each) across the entire task. The contingency between the predictor and the event is 100%, while the contingency for all other shape co-occurrences was equated at 33% (see Figure 5-2). All participants received the same sequences in the same order. Each shape was presented for a maximum duration of 1250 ms, with a further 250 ms interstimulus interval between shape presentations. If the participant pressed the wrong button or failed to press the correct button within the 1250 ms window, an appropriate error message (e.g., "Only press the yellow button for a yellow shape" or "Oops, you forgot to push the yellow button for the yellow shape") appeared to inform them of their mistake (with this also read aloud to the MLD participants). The task took approximately 10 minutes to complete. RT was recorded as the primary index of performance. In order to document implicit learning of the shape sequences, RT to green was compared to RT to yellow, because the former was always part of the predictable pattern, while the latter never was. Therefore, a RT difference score was calculated by subtracting the RT to the green shape from the RT to the yellow shape. In order to account for individual differences in visuomotor speed, this difference score was then divided by the participant's RT to the yellow shape, considered his/her baseline RT. A small minority of participants may find this task difficult, primarily because of attentional demands. Therefore, an *a priori* criterion was set for the omission of a participant's data. If a participant had more than one-third of his/her statistical learning data missing or incorrect (or a combination of these two), then his/her data were treated as invalid. RT to the first 10% of green and 10% of yellow shapes were omitted from data analysis and treated as part of "warm-up" to the task. The remaining 90% of green and 90% of yellow shape appearances were divided in half. A difference in proportional RT was calculated for the first and second halves of the task. The gain in proportional RT between the first and second halves of the task was used to indicate a "learning effect".

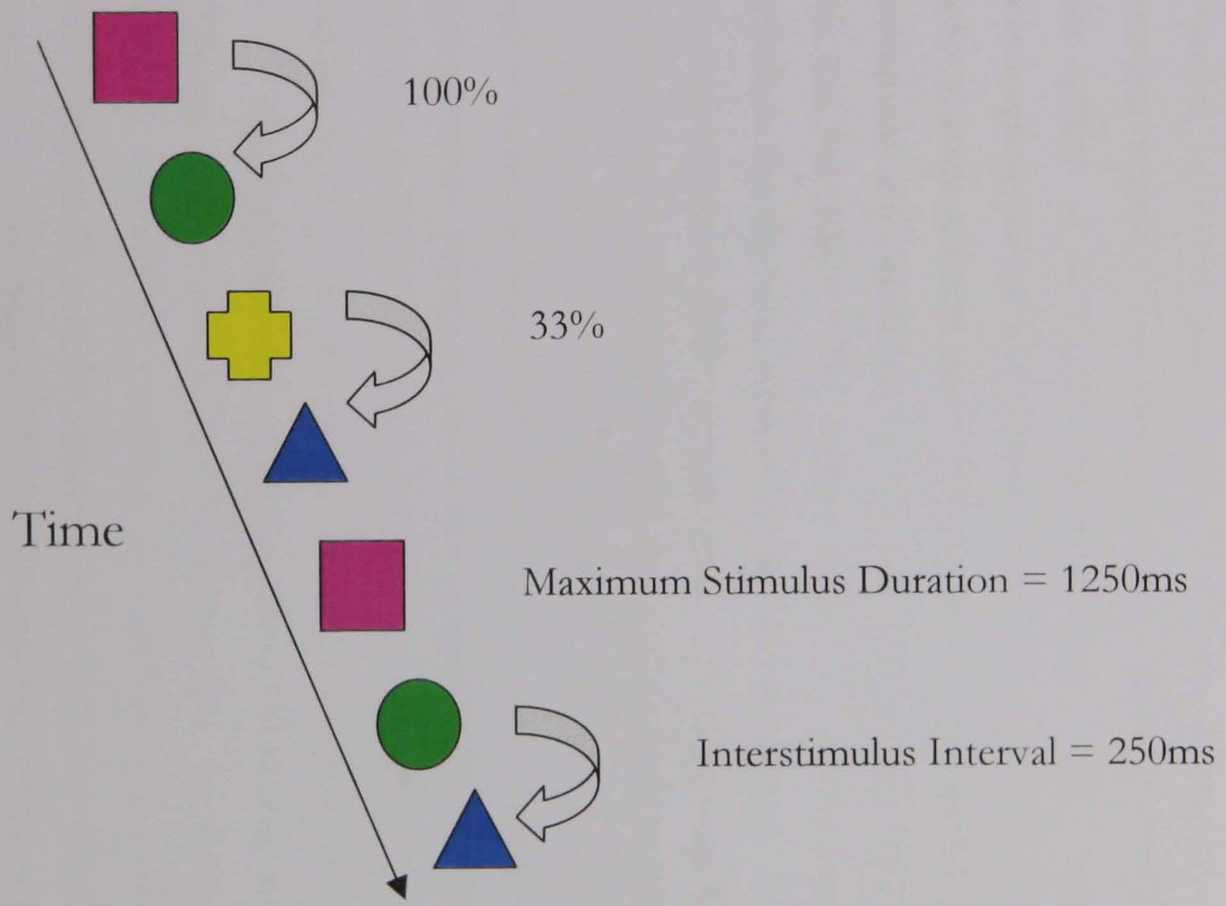


Figure 5–2. Statistical Learning Task Format:

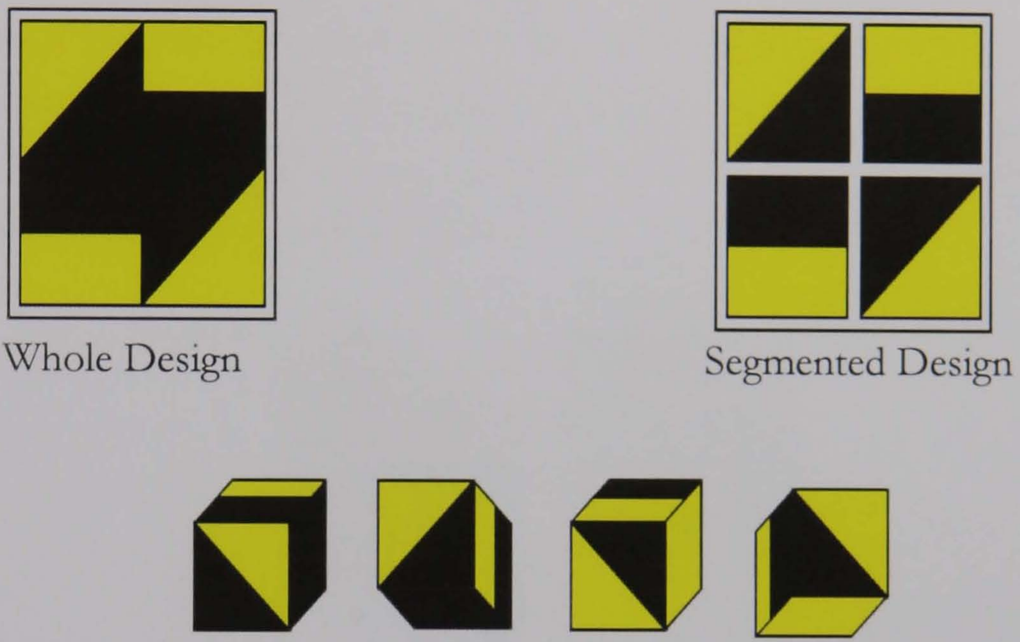
The structure of the statistical learning task required the participant to press the green, left button, when they saw the green shape and the yellow, right button, when the yellow shape appeared. The shape co-occurrences are presented above. The green circle appeared 100% of the time following the pink square, whereas other shape co-occurrences were equated at 33% likelihood. The maximum stimulus duration and interstimulus interval are also noted.

5.3.2 Central Coherence

Visuospatial:

The Children's Embedded Figures Test (Witkin et al., 1971) requires participants to find as quickly as possible a simple object (e.g., a triangle), which is hidden within a larger, more complex and meaningful figure (e.g., a house; see Figure 2-1). Participants were instructed to find the hidden figure (presented on a transparent acetate) as quickly as possible, but only to indicate this when they were sure they had located it. If a participant provided an incorrect answer, s/he was informed that an error had occurred and the clock was restarted. Scoring is based on number correct and time needed to locate the embedded figure. Since children with ASD have demonstrated superior performance on the Children's EFT (Shah & Frith, 1983) and in order to avoid potential ceiling and floor effects in all groups (given the wide range of participants' ages and ability levels), a hybrid of the Children's and standard versions of this task was utilised. The standard version of this task differs from the Children's version in that the more complex figure is not meaningful. Seven items were selected from the Children's EFT and eight items were taken from Form A of the standard EFT. Administration of all 15 items took approximately 15 minutes to complete. The two primary indices of performance were percent correct and average time taken per item to locate the hidden figure, with a cap of 60 seconds if no or incorrect answers were provided. These two indices were calculated separately both for the entire hybrid version (to avoid floor and ceiling effects) of the EFT and for only the items from the standard version of the task (to assess performance on only the most difficult items).

Un/Segmented Block Design (Booth, 2006; Shah & Frith, 1993) involved an additional administration of the Block Design task, very similar to the one used in the WISC-III, in which two conditions are contrasted: one in which the target design is both unsegmented, as in the original version, and one in which the target design is pre-segmented (see an example of each in Figure 5-3). There were a total of six items in each condition, four requiring four blocks (in a two by two design) for completion and two requiring nine blocks (in a three by three design) for completion. The block designs for copying were presented centrally on the computer screen using Superlab Pro software. Initially, participants were asked to copy whole (i.e., unsegmented) designs using black and yellow blocks, like those used in the British Ability Scales (Elliot, 1996). Each block has one completely yellow side, one completely black side, two sides that are half yellow and half black bisected horizontally, and two that are half yellow and half black bisected diagonally. In a subsequent session, participants were asked to copy designs that had been presegmented and performance was compared between the two conditions. This test was administered during subsequent testing sessions to the WISC-III, so that Block Design performance (and therefore the IQ score) was not spoiled. In order to account for baseline RT, in addition to calculating the RT difference between unsegmented and presegmented Block Design performance, a percentage savings score was derived by dividing the RT advantage by RT during the unsegmented condition.



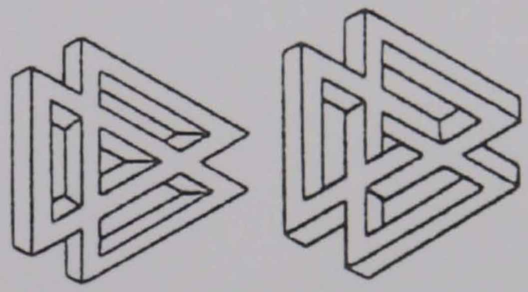
Whole Design

Segmented Design

Figure 5–3. Examples of Whole and Segmented Designs Composed of Four Blocks.

Categorisation of Possible and Impossible Figures:

In this task designed by Booth (2006) and adapted from Young and Deregowski (1981), Robinson and Wilson (1973), and Térouanne (1980), 10 geometric figures, each presented in their possible and globally impossible forms (for a total of 20 stimuli), were individually presented in a random order in the centre of the computer screen using Superlab Pro software (see Figure 5-4 for an example). To explain the concept of possibility, the following instructions were utilised: "One of these shapes could be real and could be made out of wood, while one of these shapes could not because there is something wrong." To familiarise the participants with the task, six practice items were administered; the first two showed two shapes side by side, one a possible figure and the other a globally impossible figure. The participants were asked to indicate which was possible by touching it (with words again read aloud to lower IQ participants throughout). After two examples in this format, the format was changed so that only one shape was shown and the participant was asked to indicate whether this single shape was possible or impossible by touching one of the corresponding words "possible" or "impossible" just below the shape to the left and right, respectively. During practice, the participant received feedback as to whether his or her answers were correct and if incorrect, an explanation was provided as to why it was wrong. After demonstrating that the participant understood the concepts of im/possibility, they were asked to indicate as quickly as possible whether each of the 20 objects that followed was possible or impossible by choosing the corresponding word. In total, the task took approximately five minutes to complete. Performance indices were participants' accuracy in identifying possible and impossible figures as well as their RT on correctly identified possible and impossible figures.



Possible Figure Impossible Figure

Figure 5–4. Example of a Pair of Matched Possible and Impossible Figures.

Navon Similarity Judgement Task: Utilising Navon's (1977) hierarchical figures, a novel forced-choice matching task was designed by Booth (2006). After presenting a red cross for 1000 ms to focus a participant's attention, an interstimulus interval (i.e., blank screen) appeared for 150 ms, then a target figure (e.g., the global letter "A" composed of local letters "N") was presented briefly (i.e., for 250 ms) at the top of the computer screen (see Figure 5-5). The participant was then asked to choose one of two competing figures that appeared on the bottom half of the screen depending on which one s/he thought was most like the target. Participants were told that there was no right or wrong answer for each item. One of the competing figures was composed of the same local elements but formed another global letter (e.g., the global letter "H" composed of local letters "N") while the other competing figure was composed of different local elements but formed the same global letter as the target (e.g., the global letter "A" composed of local letters "H"). In total, the task included twelve target stimuli presented at three levels of local density, resulting in a total of 36 trials. Processing bias was quantified as percentage of global matches. The task took approximately five minutes to complete. People were predicted to match more globally as the density of the local elements increases.

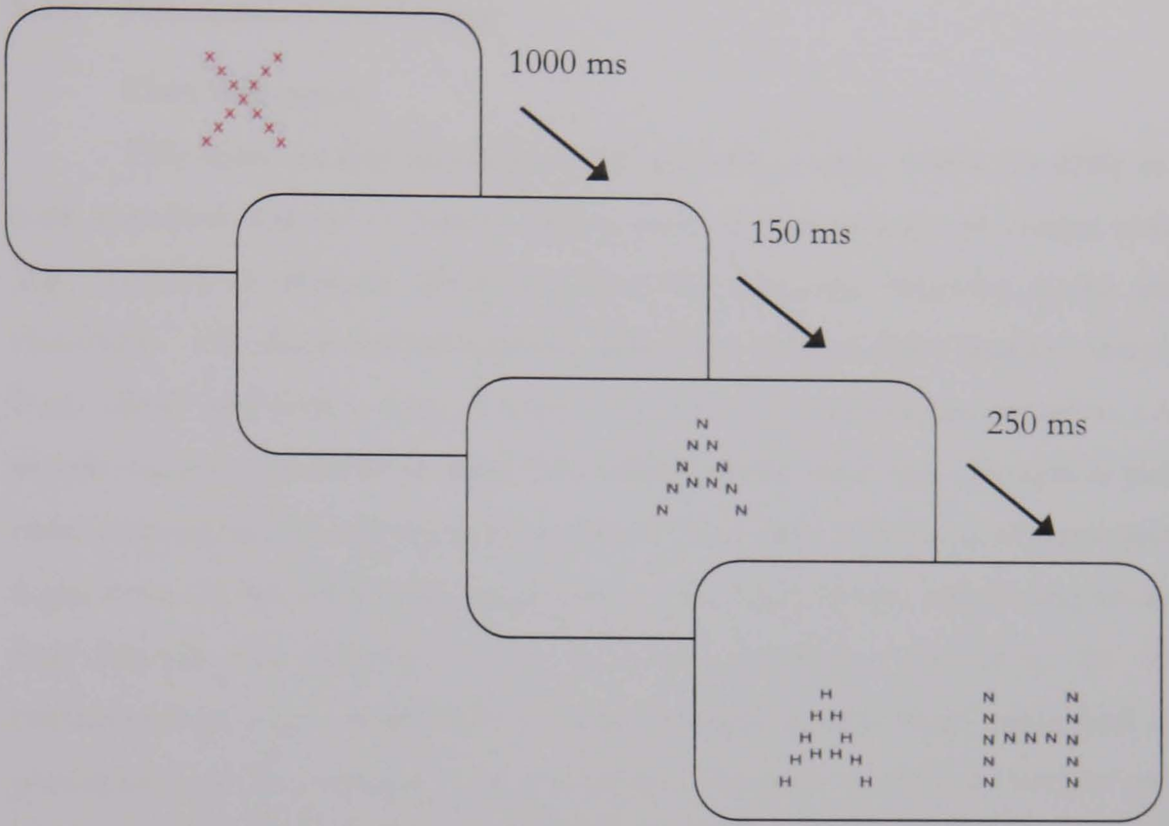


Figure 5–5. The Sequence and Duration of the Mask, Interstimulus Interval, and Stimuli Presentation in the Navon Similarity Judgment Task.

The Sentence Completion task (Happé & Booth, in preparation) measures children's use of previous context within a sentence to complete a sentence stem. The experimenter read aloud fifteen sentences (see Appendix B for a complete list of sentences) to each participant and instructed them to "say something to finish off each sentence." Ten sentences were designed to produce a conflict between making an appropriate global completion and succumbing to an inappropriate local completion. For example, the sentence stem "You can go hunting with a knife and…" can result in a response at a local (e.g., "fork") or global (e.g., "catch a bear") level. Five sentence stems that do not produce local-global conflict in their completion were used as filler items (e.g., "I was given a pen and…"). Local completions were given error scores; a score of "2" indicates a frank and obvious local completion, such as "In the sea there are fish and…*chips*" while a score of "1" was assigned to clear hesitations (i.e., 10+ seconds), thought to represent difficulty coming up with an answer counter to the "baited" stem, or when the completion was not obviously local, but was odd in quality and did not represent a good global completion. The frequency of frank error scores of

"2" were calculated separately from, but contributed to the total error score (which included the more inferential scores of "1"), resulting in two indices of performance. Administration time for this task was approximately five minutes.

5.3.3 Perceptual Functioning

Time Perception:

This thesis utilised naturalistic time perception tasks, which are likely to reflect both anecdotal reports of perfect appreciation of time passage by certain individuals (e.g., Treffert & Wallace, 2002) and everyday demands observed in the home or classroom. The three time perception tasks were adapted from Barkley, Murphy, and Bush (2001) and took a total of approximately 10-15 minutes to complete. A fixed, pseudo-randomised order of items was utilised within each time perception task. The order of presentation was the same across all three tasks and across all participants (i.e., 2 sec, 4 sec, 12 sec, 15 sec, 45 sec, 12 sec, 4 sec, 2 sec, 15 sec, and 45 sec) so that each time interval was presented twice to each participant. However, the order of presentation of each of the different time perception tasks was randomised between participants, so for example, one participant answered all time estimation questions, followed by all time production and all time reproduction questions and the next participant completed these three tasks in the opposite order (i.e., reproduction, production, and estimation). Two sets of time perception variables were calculated for all three tasks, one for examining group differences and one for correlational analyses. The first type of variable, a ratio score, was calculated through dividing the participant's answer by the actual time passage (Hornstein & Rotter, 1969). A perfect score would be one, but an overestimate would result in a ratio greater than one, and an underestimate would result in a ratio less than one. Since the ideal score of one falls in the middle of the score distribution when calculating ratios, a separate score was utilised for correlational analyses. In this case, a difference or discrepancy score (using the absolute value, as recommended by Brown (1985), to represent the magnitude of error regardless of its directionality) was calculated between the actual period of time passage and that as designated by the participant. So, if the actual period of time that passed was 45 seconds (as measured by the experimenter's stopwatch) and participant A estimated the time passage as 35 seconds while participant B estimated the time passage as 55 seconds, the difference score in both cases would be 10 seconds for that item. The following is a brief summary of the procedure for each of the time perception tasks:

Time Estimation – Using a stopwatch, the experimenter says "Go" and "Stop" after the passage of a pre-designated time period (e.g., 45 seconds) and subsequently asks the participant to estimate how much time has passed.

Time Production – The participant is asked to say "Go" and "Stop" when s/he thinks a designated amount of time (e.g., 12 seconds) has passed.

Time Reproduction – The experimenter says "Go" and "Stop" after a pre-designated time passage, and then requests the participant to copy this time passage by saying "Go" and "Stop".

5.3.4 Inspection Time

A "computer game" format was utilised to present the IT task in order to be appealing and child-friendly, similar to previous versions (e.g., Anderson, 1988). The main stimulus was a "space invader" figure with two antennae of either the same or different lengths (see Figure 5-6 below for a schematic depiction). This stimulus was presented horizontally centred, but at the bottom of the computer screen for varying durations controlled by a mask. Participants were instructed that the "space invader" figure would appear on the screen for only a very brief period of time before hiding behind a "bush" (i.e., a backward mask that remained on the screen until a response was made). The four permutations of antennae length (i.e., left antennae short-right short, left short-right long, left long-right short, or left long-right long) were randomly shown, with the participant asked to designate whether the antennae were of the same or different lengths through pressing the corresponding button. The key for "same" was on the left (the "z" key) and marked in blue while the key for "different" (the "/" key) was on the right and marked in red. Each correct response was followed by a beep, providing the participant with feedback. The participant then controlled presentation of the next stimulus by pressing the "space bar" when s/he was ready. The stimulus exposure duration was altered by varying the stimulus onset asynchrony (SOA) between the stimulus and the mask. A Parameter Estimation by Sequential Testing procedure (PEST; Taylor & Creelman, 1967) was designed to estimate 70% accuracy of responding; the associated algorithm decides whether a given SOA results in accuracy greater or less than 70%; if so, the SOA is increased or decreased, as appropriate, by a given step size. This step size is halved for every change of direction in the performance staircase (increasing SOA to decreasing SOA or vice versa), and in this way the PEST procedure hones in on the SOA required for the desired level of accuracy. The initial exposure duration used by the PEST procedure was 568 ms (40

VDU screen frames), the initial step size was 114 ms (8 frames), and the final step size was 14.2 ms (1 frame), which is the shortest SOA possible. The SOAs of the last four turns or reversals in the performance staircase were used to calculate a participant's IT. A trial consisted of four blocks, each of 25 stimulus presentations. The participants were introduced to the task during a brief practice session with feedback. This task took approximately 20 minutes to complete. The main index of performance was IT, that is, mean exposure duration at which accuracy was 70%.

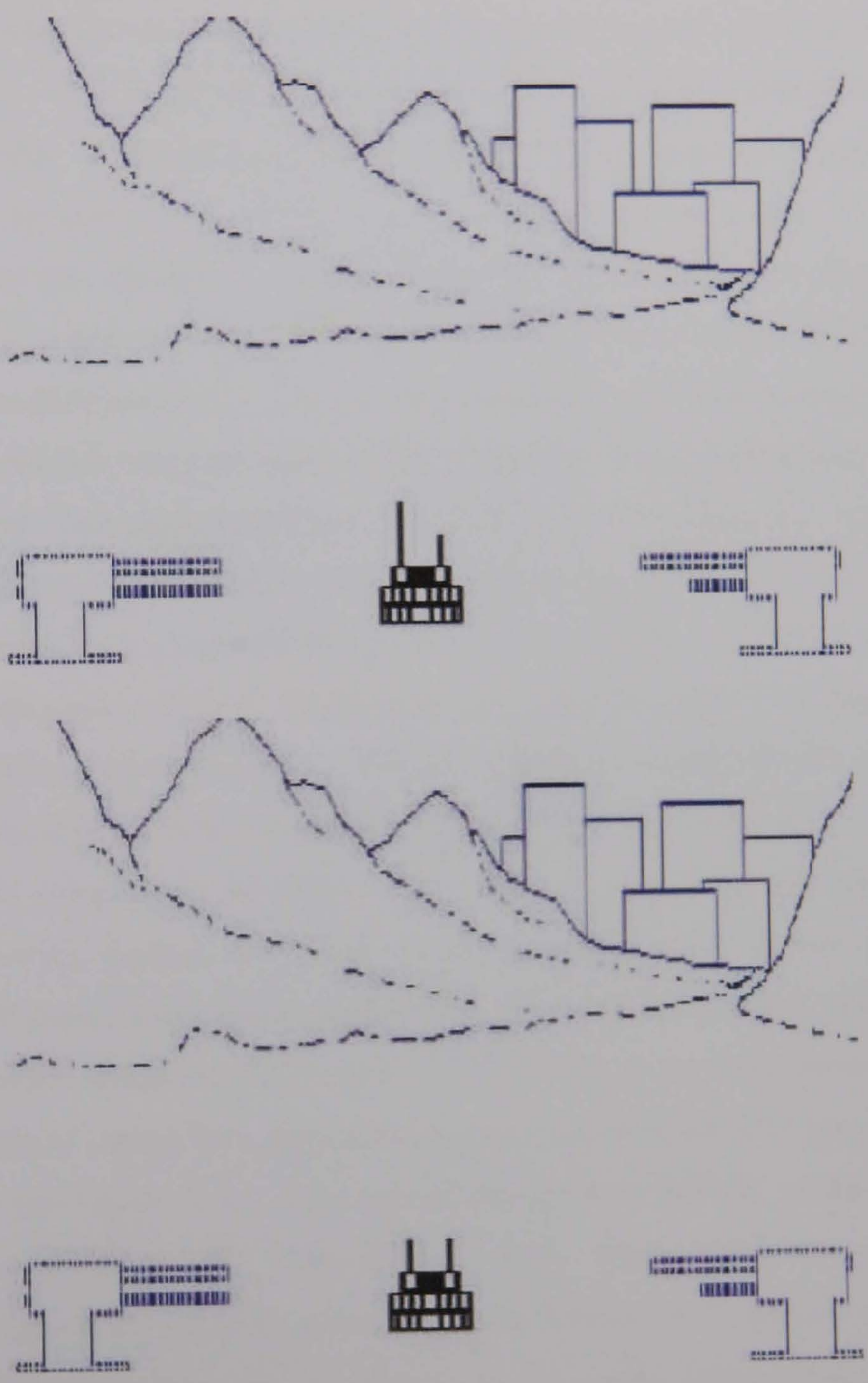


Figure 5–6. Schematic Representation of the IT Stimuli.

The "space invader" figure in the top frame has one antenna longer than the other, which would require a right button press, whereas the "space invader" figure in the second frame has equally long antennae requiring a left button press.

Chapter 6: Group Study Results

The following chapter presents group study results from the tasks described in Chapter 5. The data analytic approach is described first then the analyses are presented task by task.

6.1 Data Analytic Approach:

For all data, the first step involved examining the distribution and scatter of scores. The distributions for the key variables are depicted below in the form of box and whisker plots. The length of the box represents the difference between the 25th and 75th percentiles. The solid black line within the box represents the median score. The lines from the ends of the box to the largest and smallest values that are not outliers represent the whiskers. Case numbers are used to label outliers (o) and extremes (*). The outliers are cases with values between 1.5 and 3 box-lengths from the 75th percentile or 25th percentile. The extreme scores are cases with values more than 3 box-lengths from the 75th percentile or 25th percentile. Since sample sizes were not large, outliers may exert disproportionate influence on results. Taking a conservative approach, where there were outliers and extremes, the analyses were run with and without the outlier(s) and/or extreme(s) included and any change in results is reported.

Unless otherwise noted, all distributions of scores met criteria for homogeneity of variance and for skewness/kurtosis. Where assumptions regarding the normality of score distributions were violated, nonparametric methods were employed.

The first comparison involved ASD children versus age, gender, and IQ matched (group-wise) controls using one- or two-way analysis of variance (ANOVA) and/or Mann-Whitney tests when assumptions of parametric testing were violated (means and standard deviations for the group of TD children were also presented as an "eye-ball comparison", given their approximate group match to the ASD group in terms of mental age, see Figure 5-1). The second comparison utilised similar statistical techniques (i.e., ANOVAs and Mann-Whitney tests when necessary) to examine amongst the group of TD children potential gender differences in performance, given that amongst those diagnosed with an ASD males are vastly overrepresented and that gender differences have relevance to at least one prominent theory attempting to account for cognitive findings in ASD (Baron-Cohen, 2002). The third and final comparison was to look within each of the three groups (i.e., children with ASD, matched controls, TD children) to examine the effects of age and IQ (using Pearson or

Spearman correlations) on the variable of interest. A *p* value of .05 or less was utilised to determine if group differences across each of these comparisons was significant. In order to provide a metric of effect size independent of sample size, Cohen's *d* was calculated and provided for all group differences analyses. Cohen's conventions for the magnitude of effect size were utilised; effect sizes were defined as 'small' if $d \leq 0.2$, 'medium' if $0.2 < d < 0.8$, and 'large' if $d \geq 0.8$. Consideration was given to utilising a correction procedure for multiple comparisons (e.g., Bonferroni adjustment); however, all group-wise analyses followed *a priori* predictions. The search for group differences was therefore not arbitrary, greatly reducing the likelihood of potentially misleading, chance findings.

For the impossible figures categorisation task involving a forced choice response, signal detection theory was used to provide a measure (A') of the participants' sensitivity to the task, that is, their ability to discriminate between possible and impossible figures. A' is a nonparametric measure ranging from 0 to 1, where 1 indicates perfect sensitivity and 0.5 indicates chance performance. A' was calculated according to Grier's (1971) formula:

$$A' = 0.5 + (H - FA)(1 + H - FA) / [4H(1 - FA)]$$

where H = number of Hits, FA = number of False Alarms.

Due to time constraints and (for one task only) an aberrant computer malfunction, not all tests were administered to all participants described in Tables 5-1 and 5-2 of the Methods section. Therefore, with different group compositions across the various tasks, the group-wise matching procedures could be compromised. In order to ensure that the participant groups did not differ in age, vocabulary, or Block Design performance, these variables were re-examined during each group-wise comparison involving fewer than the maximum number of available participants. The integrity of group matching for TD males and females was also investigated in this way. However, the results of comparisons involving age, Block Design and vocabulary were re-reported only if significant (i.e., $p < .05$) differences emerged within these subgroups.

6.2 Implicit Learning

- **Children with ASD were predicted to be more efficient in their implicit learning than matched controls.**

Implicit learning was assessed through the calculation of RT advantage when responding to predictable versus unpredictable shape sequences; however, in order to account for baseline RT or motor speed, the aforementioned difference in RT was then

divided by the RT for the unpredictable shape sequence. Individuals with ASD were therefore expected to have a higher proportion score, meant to reflect learning.

6.2.1 Distribution of Scores:

Figures 6-1 and 6-2 present box plots of implicit learning performance for all participant groups.

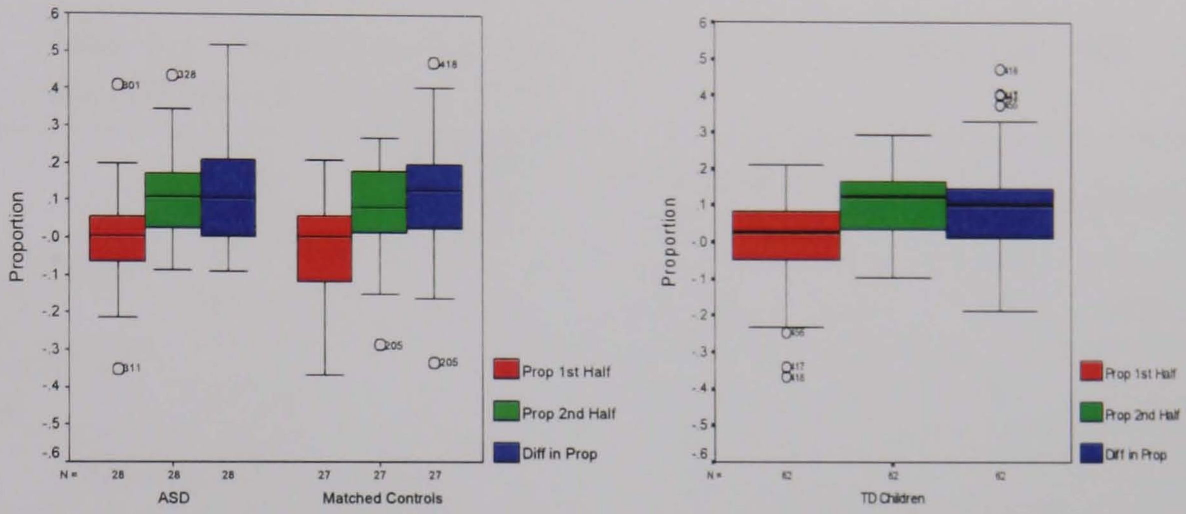


Figure 6–1. Implicit Learning Performance Amongst Children with ASD, Matched Controls, and TD Children.

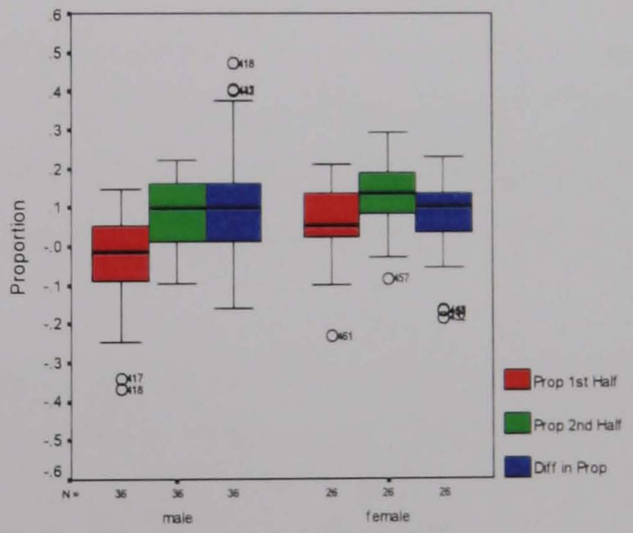


Figure 6–2. Implicit Learning Performance by Gender Amongst the TD Children.

6.2.2 ASD versus Matched Controls:

A repeated measures ANOVA was run in order to examine potential group differences in the proportion scores reflecting learning for the first and second halves of the task (see Table 6-1 for means and standard deviations). When comparing between groups, the proportional RT gain from the predictable sequence is similar (F=1.76, *p*=.19) for children with ASD and matched controls. Interactions of group by portion of the learning task were not significant (F=0.01, *p*=.95). Paired sample t-tests were run in order to assess differences in proportional RT between the first and second halves of the task; children with ASD (t=-4.09, *p*=.0003), matched controls (t=-3.65, *p*=.001), and TD children (t=-5.93, *p*<.0001) all show a significant proportional RT gain.

Table 6–1. Implicit Learning Proportional RT for Individuals with ASD and Matched Controls: Mean (SD).

	ASD (n=28)	Matched Controls (n=27)	TD Children (n=62)	F	*p*	Cohen's *d*
Prop RT 1st Half	-.004 (.14)	-.04 (.15)	.005 (.12)	0.95	.34	0.25
Prop RT 2nd Half	.12 (.12)	.08 (.13)	.10 (.10)	1.40	.20	0.32

With Outliers Removed:

After removing a total of three outliers from the ASD group and one from the group of matched controls (see Table 6-2 for revised means and standard deviations), the group differences in this learning effect remained nonsignificant (F=0.61, *p*=.44) as did the interaction term (F=1.04, *p*=.31). Paired sample t-tests were run again in order to assess differences in proportional RT between the first and second halves of the task; children with ASD (t=4.20, *p*=.0003), matched controls (t=4.78, *p*<.0001), and TD children (t=5.48, *p*<.0001) all show a significant proportional RT gain. These results confirm a learning effect in the context of this task that is comparable for all three groups.

Table 6–2. Implicit Learning Proportional RT for Individuals with ASD and Matched Controls after Outliers were Removed: Mean (SD).

	ASD (n=25)	Matched Controls (n=26)	TD Children (n=58)	F	*p*	Cohen's *d*
Prop RT 1st Half	-.005 (.10)	-.04 (.15)	.03 (.09)	1.25	.27	0.27
Prop RT 2nd Half	.09 (.10)	.09 (.11)	.10 (.10)	0.01	.93	0.00

6.2.3 Gender Differences in Implicit Learning:

Amongst the sample of TD children, girls showed a significantly greater proportional RT advantage (F=12.30, *p*=.001) when responding to a predictable versus an unpredictable sequence of shapes than did boys. The interaction between gender and condition was not significant (F=1.13; p=.29). Follow-up one-way ANOVAs revealed that the female advantage held for both halves of the task (see Table 6-3). Paired sample t-tests showed that both males (t=4.87, p<.0001) and females (t=3.39, p=.002) demonstrated a significant proportional RT gain between the first and second halves of the task.

Table 6–3. Implicit Learning Proportional RT for TD Males and Females: Mean (SD).

	Males (n=36)	Females (n=26)	F	*p*	Cohen's *d*
Prop RT 1st Half	-.03 (.12)	.06 (.10)	9.48	.003	0.81
Prop RT 2nd Half	.08 (.09)	.13 (.10)	3.93	.05	0.53

With Outliers Removed:

Overall, results (see Table 6-4) remained the same with outliers removed: girls showed a greater proportional RT advantage than boys (F=17.13, p=.0001) and the interaction term did not reach significance (F=0.15, p=.71). Follow-up one-way ANOVAs again showed a female superiority on both halves of the task. Again, paired sample t-tests showed that both males (t=4.67, p<.0001) and females (t=3.75, p=.001) demonstrated a significant proportional RT gain between the first and second halves of the task.

Table 6–4. Implicit Learning Proportional RT for TD Males and Females Minus Outliers: Mean (SD).

	Males (n=34)	Females (n=25)	F	*p*	Cohen's *d*
Prop RT 1st Half	-.01 (.09)	.07 (.08)	12.23	.001	0.94
Prop RT 2nd Half	.08 (.09)	.14 (.09)	5.79	.02	0.67

6.2.4 Relationship of Age and IQ with Implicit Learning Performance:

Pearson correlations were run to examine the relationship between difference in implicit learning proportional RT and age and IQ across the three participant groups (see Table 6-5). The pattern of results is most notable for the lack of significant findings. Implicit learning performance remained independent of age and IQ for all three groups, regardless of the exclusion of outliers from the groups of matched controls and TD children.

Table 6–5. Correlations between Difference in Implicit Learning Proportional RT and Age and IQ Amongst ASD Children, Matched Controls, and TD Children (Results after the Removal of Outliers Presented in Parentheses).

Difference in Stat Learning Prop RT	Prop RT in ASD (n=28)	Prop RT in Matched Controls (n=27; 25)	Prop RT in TD Children (n=62; 58)
Age	.01	.11 (.34)	.23 (.18)
Vocab	-.04	.04 (-.30)	-.09 (-.06)
Block Design	-.15	.08 (-.21)	-.19 (-.13)
FSIQ	-.10	.06 (-.28)	-.18 (-.13)

6.3 The Embedded Figures Test

- Individuals with ASD were predicted to outperform age and IQ matched controls, and performance in TD males was expected to surpass that in TD females in terms of their accuracy and speed in finding hidden figures in the EFT.

The main indices of performance were percent correct and average time taken to find each figure. These indices were measured for both the entire hybrid version of the EFT and the subset of items selected from the standard version of the EFT.

6.3.1 Distribution of Scores:

Figures 6-3 to 6-6 present box plots of EFT performance for all participant groups.

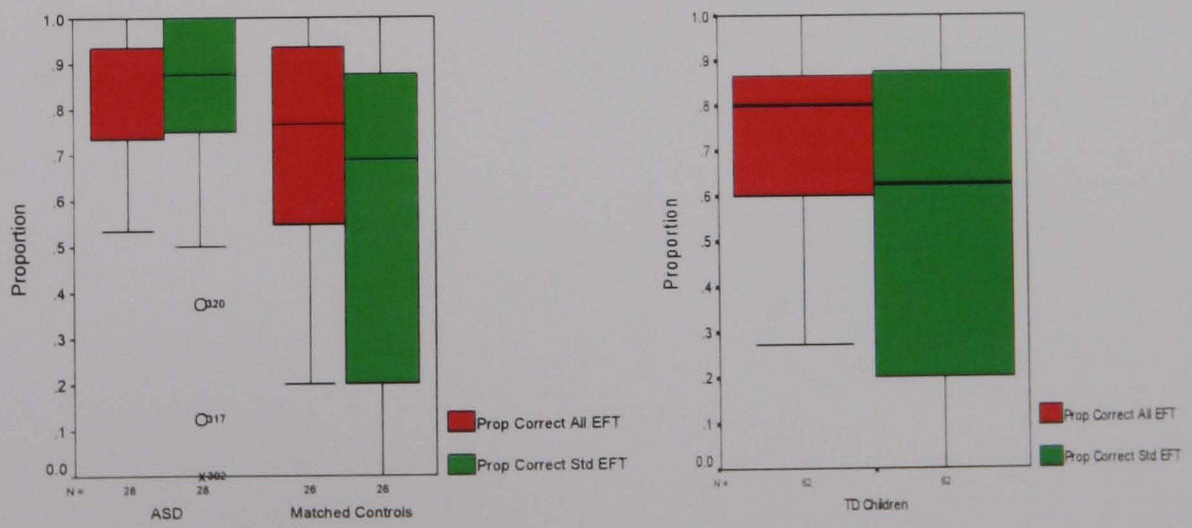


Figure 6–3. Proportion Correct of EFT Items Amongst Children with ASD, Matched Controls, and TD Children.

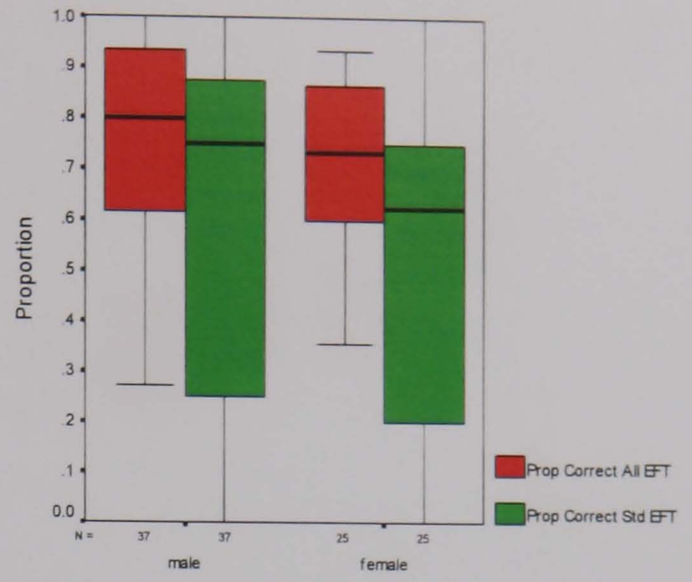


Figure 6–4. Proportion Correct of EFT Items for Males and Females Amongst the TD Children.

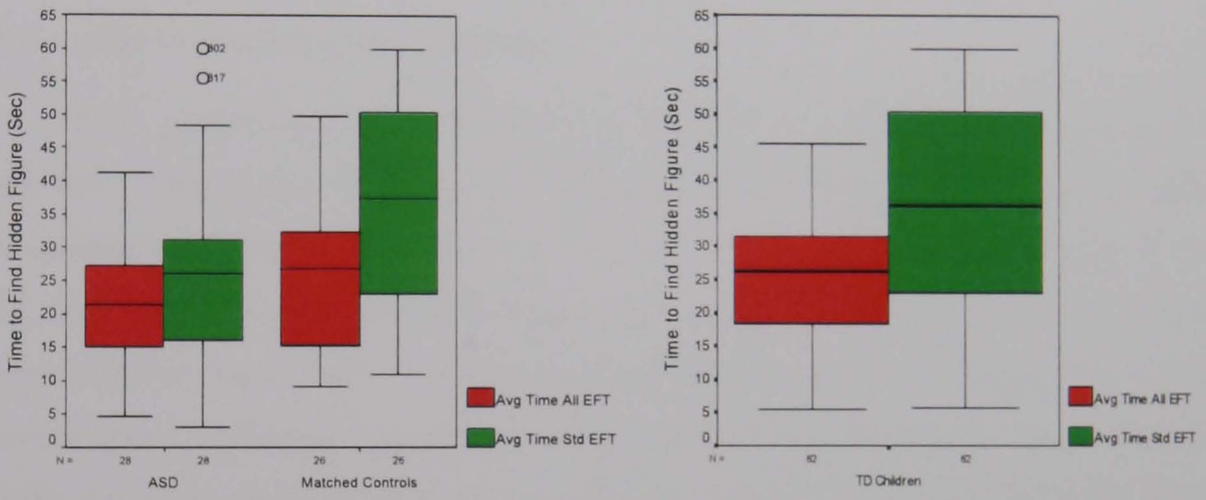


Figure 6–5. Average Time (per Figure) to Finding Hidden Figures on the EFT Amongst Children with ASD, Matched Controls, and TD Children.

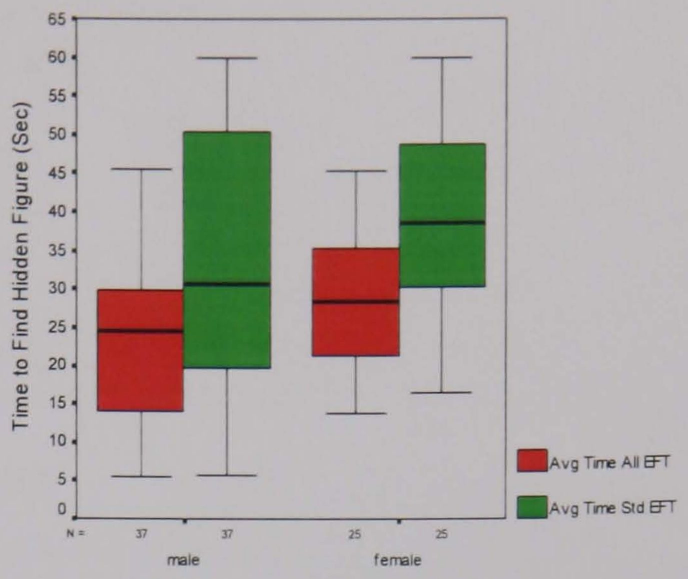


Figure 6–6. Average Time (per Figure) to Finding Hidden Figures on the EFT Amongst Males and Females within the Group of TD Children.

6.3.2 ASD versus Matched Controls:

EFT performance for the ASD and matched control groups is presented in Table 6-6. Consistent with predictions, individuals with ASD displayed more accurate and quicker performance than matched controls on the entire hybrid version of the EFT used here, although only differences in percentage of correctly identified hidden figures reached significance. When focussing solely on the standard EFT items, between group differences involving average time to find the hidden shape reached significance. The index of accuracy (i.e., percent correct) for the standard EFT items failed Levene's Test of Equality of Error Variances (F=6.58, *p*=.01); therefore, Mann-Whitney was used in order to assess differences in ranking of scores. Percentage of correctly located hidden figures amongst the standard EFT items was significantly higher for the ASD group than the matched control group, indicating an ASD superiority in the ability to hone in on a hidden local shape amongst distracter elements.

Table 6–6. EFT Performance by Children with ASD and Matched Controls: Mean (SD).

	ASD (n=28)	Matched Controls (n=26)	TD Children (n=63)	F/Z	*p*	Cohen's *d*
Average Time All EFT Items	21.51 (8.38)	25.73 (10.98)	26.25 (10.87)	2.55	.12	0.43
% Correct All EFT Items	84 (14)	73 (22)	73 (21)	5.00	.03	0.60
Average Time Std EFT Items	26.02 (13.68)	37.07 (16.20)	36.74 (15.79)	7.37	.01	0.74
% Correct Std EFT Items	78 (26)	56 (36)	55 (34)	2.39▲	.02	0.72

▲Z value from Mann-Whitney

With Outliers Removed:

Two outliers from the ASD group were removed from the data for average time spent on the standard EFT items, while three outliers from the ASD group were removed from the data measuring percentage of correctly located hidden figures amongst the standard EFT items only. After removal of these outliers, both average time spent on these items and percentage of correctly located hidden figures failed Levene's Test of Equality of Error Variances (Average Time on Standard EFT Items, F=6.20, *p*=.02; Percent Correct Standard EFT, F=26.11, *p*<.001). Mann-Whitney was therefore used in order to assess differences in the ranking of scores. ASD children had shorter response times (n=26, M=23.58 ± 10.73; Z=2.88, *p*=.004, *d*=0.98) and were more accurate (n=25, M=86 ± 14; Z=3.06, *p*=.002, *d*=1.10) in locating the hidden figures from the standard version of the EFT.

6.3.3 Gender Differences in Embedded Figures Test performance:

When examining gender differences in EFT performance (see Table 6-7), males were significantly faster than females in terms of average time per item completed across the entire hybrid version of the EFT. The relationship between male and female performance paralleled the relationship between ASD and matched control group performance; males were both more accurate and faster than females in identifying embedded figures.

Table 6–7. Gender Differences in EFT Performance: Mean (SD).

	Male (n=37)	Female (n=26)	F	*p*	Cohen's *d*
Average Time All EFT Items	23.63 (10.13)	29.96 (10.99)	5.56	.02	0.60
% Correct All EFT Items	77 (18)	68 (23)	2.67	.11	0.44
Average Time Std EFT Items	34.67 (16.98)	39.81 (13.60)	1.60	.21	0.33
% Correct Std EFT Items	60 (35)	49 (32)	1.40	.24	0.33

6.3.4 Relationship of Age and IQ with EFT performance:

Pearson and Spearman correlations were run to examine the relationship between EFT performance and age and IQ across the three participant groups (see Tables 6-8, 6-9, and 6-10). Amongst the TD children, EFT performance was robustly related to Block Design performance as well as age. The relationship of EFT performance with Block Design performance also held for the matched control group, though age relationships disappeared. For the ASD group there were no significant correlations with IQ or age. The difference in the correlations between EFT and Block Design performance was not significant when comparing individuals with ASD to TD children (z_{r1r2}=1.36, p=.17) or to matched controls (z_{r1r2}=1.25, p=.21). However, the difference in the relationship between age and EFT performance for individuals with ASD versus TD children approached the significance threshold (z_{r1r2}=1.86, p=.06). Pearson and Spearman correlations were rerun with outliers excluded. After removing one outlier from the group of TD Children, EFT remained strongly related to both age and Block Design performance. Removal of outliers from the ASD group showed that correlations of standard EFT performance with age and IQ measures remained unchanged and nonsignificant.

Table 6–8. Correlations between EFT Performance and Age and IQ Amongst Children with ASD (Results after the Removal of Outliers Presented in Parentheses).

ASD Only	% Correct All EFT Items (n=28)	% Correct Std EFT Items‡ (n=28; 25)	Average Time All EFT Items (n=28)	Average Time Std EFT Items‡ (n=28; 26)
Age	.15	.23 (.20)	-.10	-.08 (-.04)
Vocab	.06	-.07 (-.16)	-.05	-.03 (.04)
Block Design	.21	.17 (.20)	-.29	-.16 (-.30)
FSIQ	.15	.00 (-.03)	-.19	-.10 (-.07)

‡-Spearman's rho utilised

Table 6–9. Correlations between EFT Performance and Age and IQ Amongst Matched Controls.

Matched Controls (N=26)	% Correct All EFT Items	% Correct Std EFT Items‡	Average Time All EFT Items	Average Time Std EFT Items
Age	-.03	.30	.07	-.28
Vocab	.41*	.34	-.41*	-.33
Block Design	.64**	.47*	-.67**	-.48*
FSIQ	.56**	.43*	-.58**	-.43*

*p<.05, **p<.01

‡-Spearman's rho utilised

Table 6–10. Correlations between EFT Performance and Age and IQ Amongst TD Children (Results after the Removal of Outliers Presented in Parentheses).

All TD Children	% Correct All EFT Items (n=63; 62)	% Correct Std EFT Items (n=63)	Average Time All EFT Items (n=63; 62)	Average Time Std EFT Items (n=63)
Age	.46** (.41**)	.49**	-.47** (-.45**)	-.48**
Vocab	-.12 (.03)	.18	.10 (-.03)	-.17
Block Design	.40** (.36**)	.42**	-.40** (-.37**)	-.45**
FSIQ	.20 (.26*)	.38**	-.22 (-.27*)	-.40**

*p<.05, **p<.01

6.4 Un/Segmented Block Design

- **Individuals with ASD were expected to derive less benefit from presegmentation of the block designs than were matched controls.**

The main index for assessing the benefit from presegmentation was a percentage savings score calculated by taking the RT difference between unsegmented and presegmented Block Design performance and dividing this difference by the RT during the unsegmented condition; thus, accounting for baseline speed on this task. Due to time constraints at several schools (this was one of the last tasks administered to participants), only 25 individuals with ASD and 19 matched controls were administered both the unsegmented and segmented versions of the Block Design task.

6.4.1 Distribution of Scores:

Figures 6-7 and 6-8 present box plots of un/segmented Block Design performance for all participant groups.

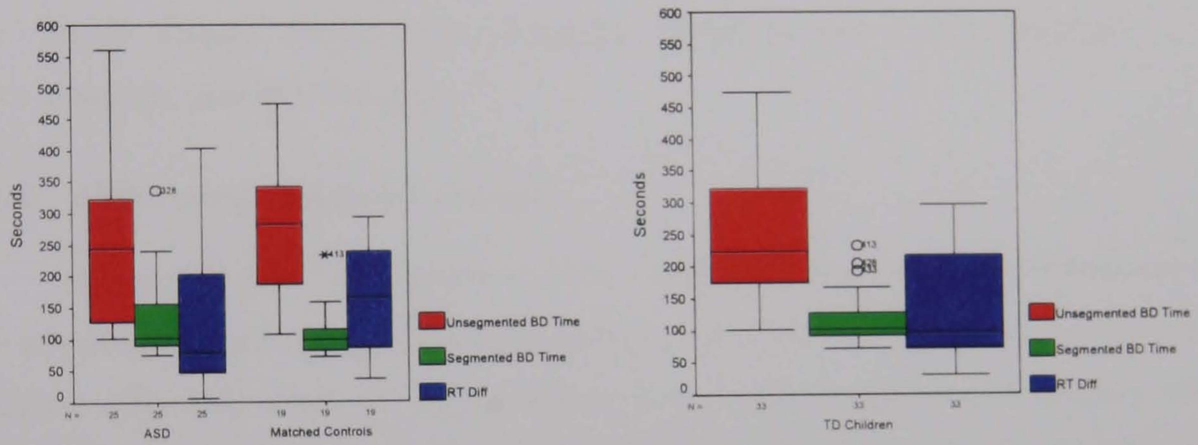


Figure 6–7. Time to Complete and RT Difference Between Unsegmented and Segmented Block Design Amongst Children with ASD, Matched Controls, and TD Children.

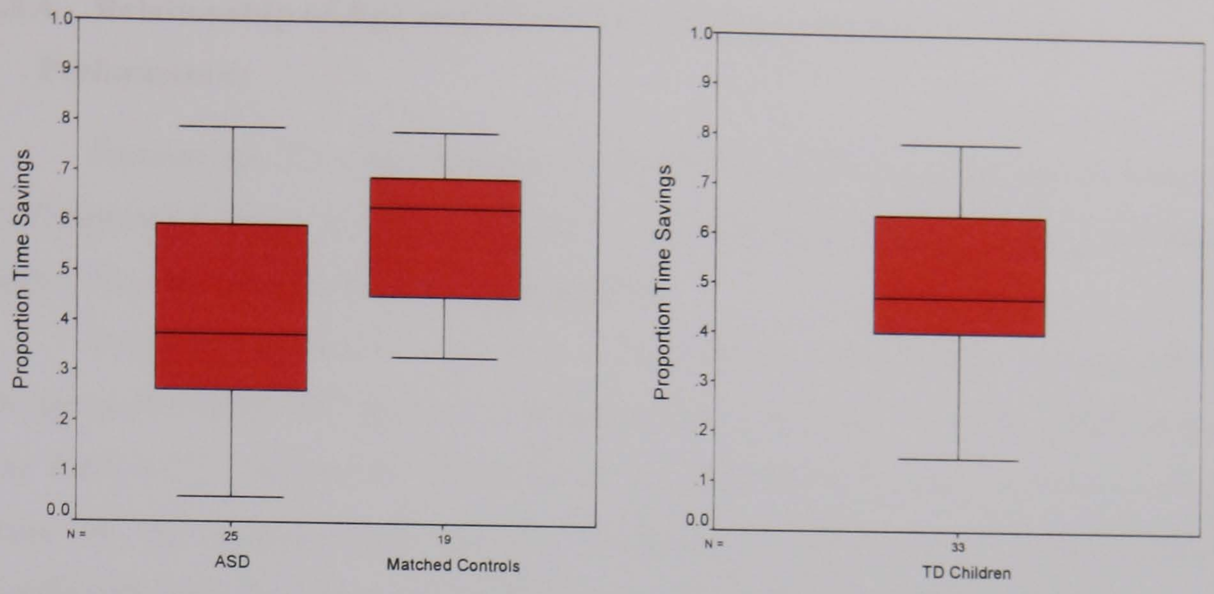


Figure 6–8. Proportion Savings in RT for Unsegmented versus Segmented Block Design Performance Amongst Children with ASD, Matched Controls, and TD Children.

6.4.2 ASD versus Matched Controls:

A one-way ANOVA was run in order to examine potential group differences in RT advantage gained through presegmentation of the block designs (see Table 6-11). Children with ASD displayed less advantage from block design presegmentation than did matched controls: though the results for RT difference were not significantly different, the percentage savings score was significantly higher for matched controls than for children with ASD.

Table 6–11. Differences in Un/Segmented Block Design Performance for Children with ASD, Matched Controls, and TD Children: Mean (SD).

	ASD (n=25)	Matched Controls (n=19)	TD Children (n=33)	F	*p*	Cohen's *d*
RT Difference	127.24 (110.66)	169.11 (86.86)	139.42 (91.34)	1.85	.18	0.42
% Savings Score	42.74 (20.09)	57.43 (13.67)	50.28 (15.80)	7.49	.01	0.85

6.4.3 Gender Differences in Block Design performance:

As previously stated, the Un/Segmented Block Design task was one of the last tasks in the battery and as such, was one of the first to be excluded in cases of time constraint; therefore, only 33 of the TD children received the task. Gender differences in performance were not examined because none of the 33 TD children were female.

6.4.4 Relationship of Age and IQ with Un/Segmented Block Design Performance:

Because the IQ score included the Block Design subtest, correlations between Un/Segmented Block Design performance and IQ were limited to the Vocabulary subtest that was administered to all participants.

Pearson correlations were run to examine the relationship between Block Design performance and age and vocabulary score across the three participant groups (see Table 6-12). Neither the RT difference in performance nor the percentage savings score on the presegmented and the unsegmented Block Design task correlated significantly with vocabulary or with age in any of the three participant groups.

Table 6–12. Correlations between Un/Segmented Block Design Performance and Age and Vocabulary Amongst ASD Children, Matched Controls and TD Children.

Un/Seg BD	RT for Un/Seg BD in ASD (N=25)	% Savings in ASD (N=25)	RT for Un/Seg BD in Matched Controls (N=19)	% Savings in Matched Controls (N=19)	RT for Un/Seg BD in TD Children (N=33)	% Savings in TD Children (N=33)
Age	.31	.33	.08	.20	-.07	.15
Vocab	-.37	-.36	-.24	-.20	.14	.14

6.5 Categorisation of Possible and Impossible Figures

- Matched controls were predicted to outperform children with ASD when asked to identify impossible figures because of the need for integrative global processing.

Several key indices were utilised to assess performance and response bias. Accuracy was assessed separately for correct identification of possible and impossible figures. RT to these correct identifications was also assessed. Finally, A' was calculated for this forced choice task to provide a summary index of sensitivity to the difference between possible and impossible figures.

6.5.1 Distribution of Scores:

Figures 6-9 to 6-14 present box plots of performance on the im/possible figures categorisation task for all participant groups.

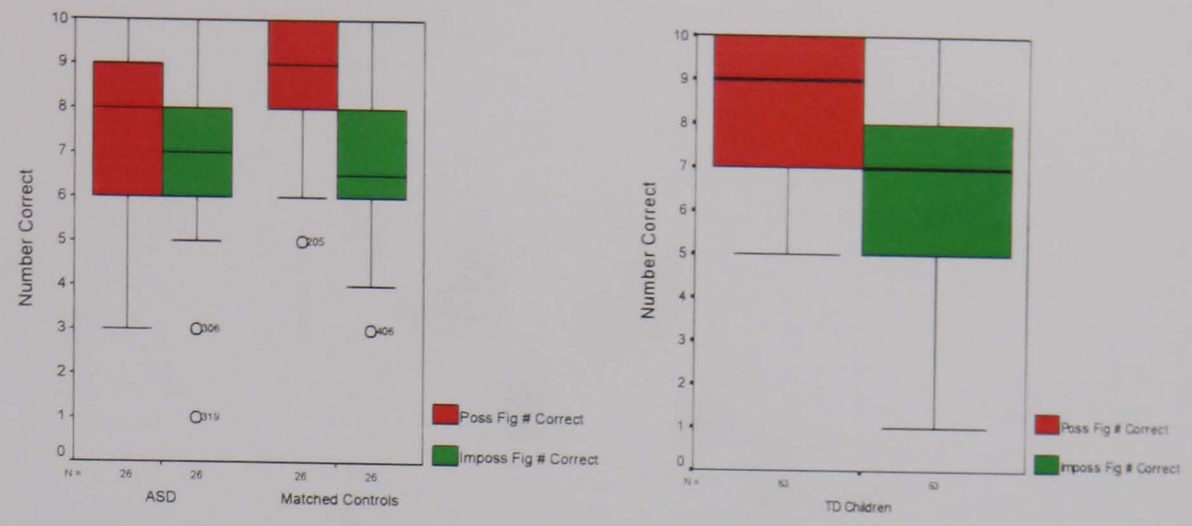


Figure 6–9. Number of Correctly Identified Im/Possible Figures by Children with ASD, Matched Controls, and TD Children.

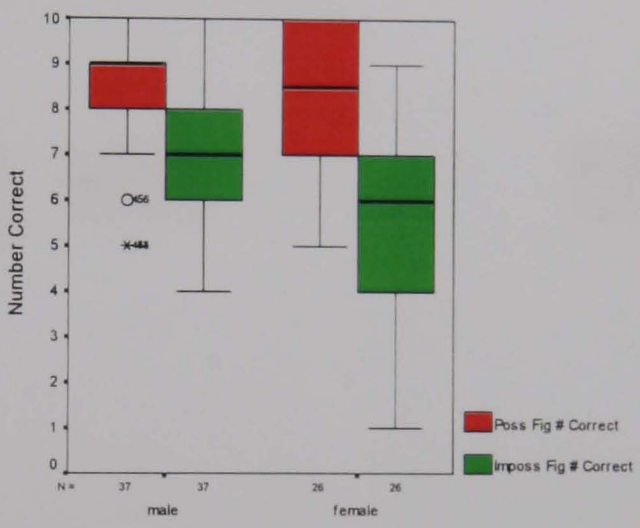


Figure 6–10. Number of Correctly Categorised Im/Possible Figures by Male and Female TD Children.

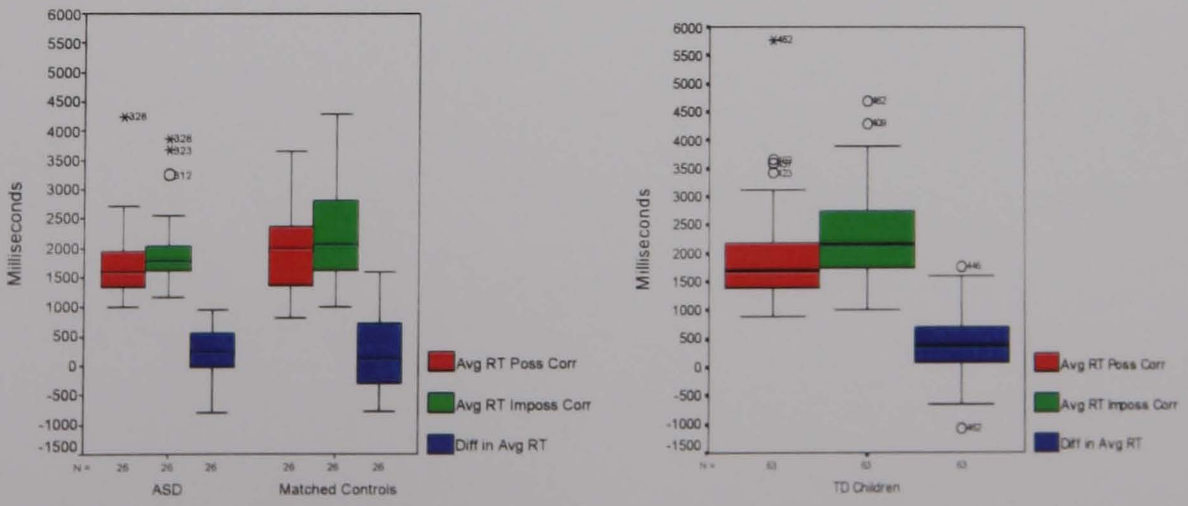


Figure 6–11. RT to Correctly Categorised Im/Possible Figures Amongst Children with ASD, Matched Controls, and TD Children.

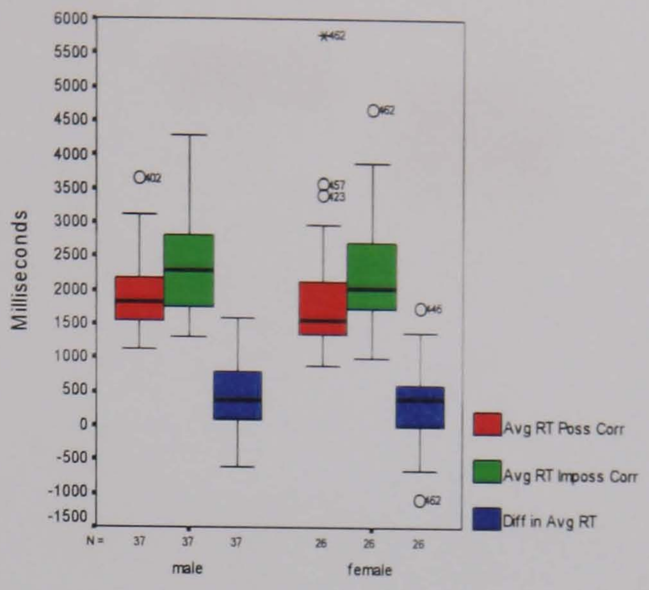


Figure 6–12. RT to Correctly Categorised Im/Possible Figures by Males and Females Amongst the TD Children.

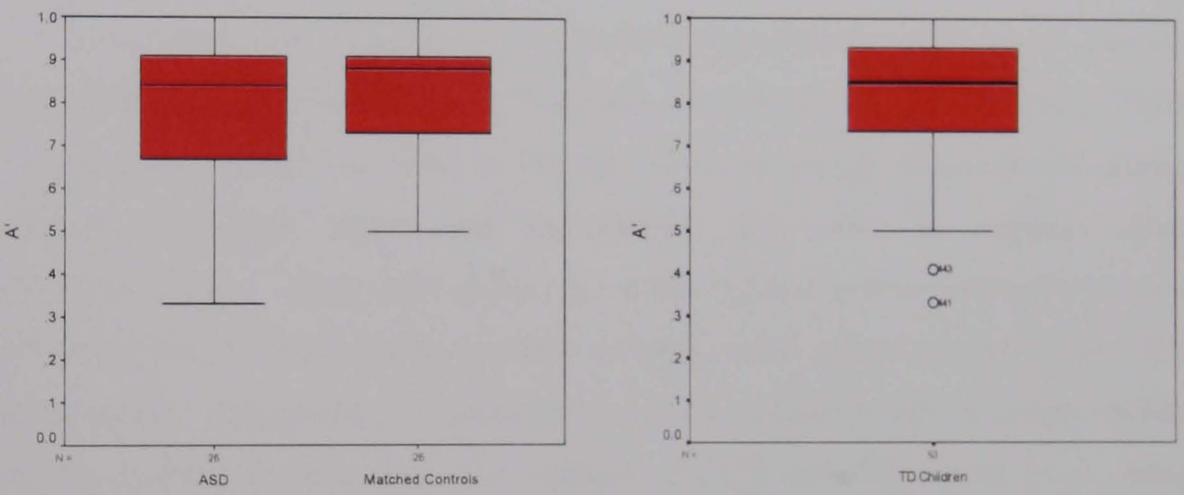


Figure 6–13. A' Scores Amongst Children with ASD, Matched Controls, and TD Children.

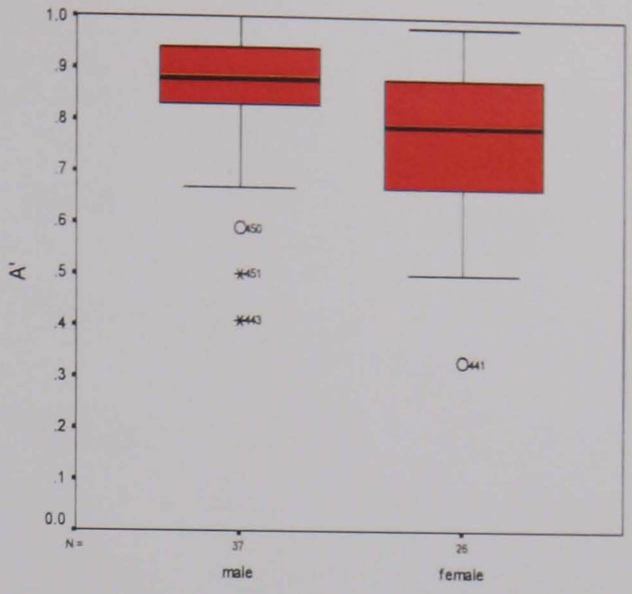


Figure 6–14. A' Scores for Males and Females Amongst the TD Children.

6.5.2 ASD versus Matched Controls:

A one-way ANOVA (except for number of possible figures correctly identified, which failed Levene's Test of Error Variances: F=4.26, *p*=.04; thus, a Mann Whitney Test was used) was run in order to examine potential group differences in correctly identifying impossible figures and the average time taken to correctly identify im/possible figures. Table 6-13 shows that ASD children perform comparably to age and IQ matched controls on all measures of im/possible figure categorisation. When looking within individuals but across tasks, it is noticeable that amongst matched controls (t=4.16, *p*<.001) and TD children (t=7.72, *p*<.001), there is a stronger decrement in accuracy of identifying possible versus impossible figures compared to that observed in the group of ASD children (t=1.28, *p*=.21).

Table 6–13. Im/Possible Figure Categorisation for ASD and Matched Control Children: Mean (SD).

	ASD (N=26)	Matched Controls (N=26)	TD Children (N=63)	F/Z	*p*	Cohen's *d*
Possible Figure # Correct (Max=10)	7.69 (1.95)	8.50 (1.42)	8.40 (1.50)	1.44▲	.15	0.47
Impossible Figure # Correct (Max=10)	7.00 (2.06)	6.88 (1.82)	6.40 (1.96)	0.05	.83	0.06
Avg RT for Correctly Identified Possible Figures	1773.65 (677.42)	2004.54 (749.03)	1938.86 (806.04)	1.36	.25	0.32
Avg RT for Correctly Identified Impossible Figures	2011.58 (661.57)	2220.81 (769.40)	2296.89 (720.43)	1.11	.30	0.29
Difference in Avg RT to Correctly Identified Figures	237.92 (429.11)	216.27 (606.84)	358.03 (566.34)	0.02	.88	0.04
A' for Sensitivity	.80 (.16)	.84 (.13)	.82 (.15)	0.88	.35	0.27

▲Z value from Mann-Whitney

With Outliers Removed:

Overall, removing outlying scores from each of the groups did not significantly alter the results or reveal significant group differences. Group differences in the number of correctly identified possible figures failed to reach significance (Z=1.69, *p*=.09) after the removal of one outlying data point from the group of matched controls (M=8.64 ± 1.25). The number of correctly identified impossible figures did not differ between groups (F=0.70, *p*=.41) after the removal of two outlying data points from the ASD group (M=7.42 ± 1.47) and one outlying data point from the matched control group (M=7.04 ± 1.67). Similarly, after removing one outlying data point from the ASD group in average RT to correctly identified possible figures (M=1674.88 ± 462.36) and three outlying data points from the ASD group in average RT to correctly identifying impossible figures (M=1804.57 ± 316.21), comparisons to matched controls remained nonsignificant (RT to Possible Figures: Z=1.56, *p*=.12; RT to Impossible Figures: Z=1.64, *p*=.10). The pattern of performance within individuals but across tasks remained the same, with possible figures more readily identified than impossible figures by the group of matched controls (t=4.48, *p*<.001), but no difference in performance for the group of ASD children (t=0.68, *p*=.50).

6.5.3 Gender Differences in Im/Possible Figure Categorisation:

A one way ANOVA indicated that males more accurately identified impossible figures in the context of this forced choice task than did females, and the related sensitivity index (i.e., A') demonstrated better male than female performance on the task (see Table 6-14). Males (t=5.67, *p*<.001) and females (t=5.88, *p*<.001) demonstrated relatively equal decrements in performance when asked to identify possible as opposed to impossible figures.

Table 6–14. Gender Differences in Im/Possible Figure Categorisation: Mean (SD).

	Male (N=37)	Female (N=26)	F/Z	*p*	Cohen's *d*
Possible Figure # Correct (Max=10)	8.49 (1.41)	8.27 (1.64)	0.33▲	.74	0.14
Impossible Figure # Correct (Max=10)	7.05 (1.67)	5.46 (1.98)	11.91	.001	0.87
Avg RT for Correctly Identified Possible Figures	1936.70 (587.74)	1941.92 (1055.37)	0.001	.98	0.01
Avg RT for Correctly Identified Impossible Figures	2317.27 (655.59)	2267.88 (816.56)	0.07	.79	0.07
Difference in Avg RT to Correctly Identified Figures	380.57 (517.97)	325.96 (638.18)	0.14	.71	0.09
A' for Sensitivity	.85 (.13)	.77 (.15)	5.08	.03	0.57

▲Z value from Mann-Whitney

With Outliers Removed:

The removal of outlying scores for the three RT variables did not alter results significantly; males and females did not differ in their RT to correctly identified im/possible figures, or in the difference of these RTs. Removal of four outlying scores from the male subgroup's number of correctly identified possible figures did not alter the results; there were no significant gender differences and the decrement in performance in identifying possible as compared to impossible figures remained (t=5.87, *p*<.001). For the sensitivity index, A', the removal of three outliers from the male subgroup and one outlier from the female subgroup resulted in data that violated

Levene's Test of Equality of Error Variances (F=7.26, p=.01) when attempting a one-way ANOVA. After comparing the rankings of scores using a Mann-Whitney nonparametric test, results remained significant (Z=2.68, p=.01), showing a greater sensitivity to the difference in possibility amongst males, which may be partially driven by the better male performance in correctly identifying impossible figures and a slight tendency amongst females to say everything is possible.

6.5.4 Relationship of Age and IQ with Im/Possible Figure Categorisation:

Pearson and Spearman correlations were run to examine the relationship between im/possible figure categorisation and age and IQ across the three participant groups (see Tables 6-15, 6-16, and 6-17). These correlations revealed both unique and shared relationships across the three groups. Amongst the ASD and the matched control groups, there was a strong relationship between estimated IQ and number of correctly identified possible figures, but not for the TD children, for whom age was the strongest and only significant correlate. Supporting this contention, the correlation between estimated full scale IQ and number of correctly identified possible figures was significantly different for the ASD and TD children (z_{r1r2}=3.73, p=.0002).

For number of correctly identified impossible figures, Block Design performance was the crucial correlate shared by both the matched controls and TD children. In contrast, the ASD group showed no significant correlations between number of correctly identified impossible figures and age and IQ measures. Indeed, when comparing the correlations of Block Design and number of impossible figures correctly identified between individuals with ASD and matched controls, the difference reached significance (z_{r1r2}=2.01, p=.04), despite the small sample size.

Additionally, the TD group showed a significant relationship between age and number of correctly identified impossible figures. Since the matched control group showed no such relationship with age, it can be inferred that the inclusion of MLD children is altering this correlation.

Finally, for A', the sensitivity measure, IQ measures were the significant correlates within the matched control and ASD groups, whereas age, and to a lesser extent Block Design performance, were the significant correlates for the group of TD children.

Table 6–15. Correlations between Im/Possible Figure Categorisation and Age and IQ Amongst ASD Children with and without Outliers Included (Results after the Removal of Outliers Presented in Parentheses).

ASD Only	Number Correct Possible Figures‡ (n=26)	Number Correct Impossible Figures (n=26, 24)	RT to Correctly Identified Possible Figures (n=26, 25)	RT to Correctly Identified Impossible Figures (n=26, 23)	Difference in Avg RT to Correctly Identified Im/Possible Figures (n=26)	A' for Sensitivity (n=26)
Age	-.16	.34 (.43*)	-.08 (-.07)	-.09 (-.24)	-.02	.07
Vocab	.74**	.06 (.03)	.24 (.44*)	.32 (.29)	.11	.48*
Block Design	.72**	.07 (.11)	.05 (.15)	.15 (.33)	.15	.46*
FSIQ	.78**	.07 (.08)	.15 (.31)	.24 (.33)	.14	.51**

**p*<.05, ***p*<.01

‡-Spearman's rho utilised

Table 6–16. Correlations between Im/Possible Figure Categorisation and Age and IQ Amongst Matched Controls with and without Outliers Included (Results after the Removal of Outliers Presented in Parentheses).

MC	Number Correct Possible Figures‡ (n=26, 25)	Number Correct Impossible Figures (n=26, 25)	RT to Correctly Identified Possible Figures (n=26)	RT to Correctly Identified Impossible Figures (n=26)	Difference in Avg RT to Correctly Identified Im/Possible Figures (n=26)	A' for Sensitivity (n=26)
Age	.12 (.26)	.06 (.09)	.13	-.03	-.19	.09
Vocab	.42* (.35)	.30 (.31)	-.21	-.23	-.03	.63**
Block Design	.40* (.32)	.58** (.62**)	-.02	-.10	-.10	.68**
FSIQ	.37 (.29)	.46* (.49*)	-.13	-.19	-.07	.70**

**p*<.05, **p<.01

‡-Spearman's rho utilised

Table 6–17. Correlations between Im/Possible Figure Categorisation and Age and IQ Amongst TD Children with and without Outliers Included (Results after the Removal of Outliers Presented in Parentheses).

All TD Children	Number Correct Possible Figures‡ (n=63)	Number Correct Impossible Figures (n=63)	RT to Correctly Identified Possible Figures (n=63)	RT to Correctly Identified Impossible Figures (n=63)	Difference in Avg RT to Correctly Identified Im/Possible Figures (n=63)	A' for Sensitivity (n=63, 61)
Age	.57**	.36**	-.10	-.10	.02	.52** (.53**)
Vocab	.08	.14	-.17	-.18	.00	.15 (.19)
Block Design	.12	.40**	-.08	-.03	.07	.28* (.40**)
FSIQ	.14	.36**	-.14	-.12	.05	.28* (.39**)

*p<.05, **p<.01

‡-Spearman's rho utilised

With Outliers Removed:

After removing two outliers from the ASD group for number of correctly identified impossible figures, all correlations remained nonsignificant except for the relationship with age which became significant. Amongst the ASD group, one outlier was removed for RT to a correctly identified possible figure; all correlations remained nonsignificant except for the relationship with vocabulary which fell below significance. The ASD group also contained three outliers in RT to a correctly identified impossible figure. After their removal, all correlations remained nonsignificant. After removal of one outlying score from the matched control group for number of correctly identified possible figures, the correlations with vocabulary and Block Design became nonsignificant. The removal of one outlier from the matched control group in number of correctly identified impossible figures did not alter the correlations above.

Removal of two A' outliers from the group of TD children confirmed the correlations above by maintaining the relationship with age and strengthening the relationship with Block Design performance and the total IQ estimate.

6.6 Navon Similarity Judgement Task

- When asked to match hierarchically arranged letters at either a local or global level, individuals with ASD were predicted to choose more local matches than the matched controls, regardless of the density level at which the letters were presented.

The main index of performance was percentage of global matches provided, which could then be split according to the density level of the stimuli.

6.6.1 Distribution of Scores:

Figures 6-15 to 6-17 present box plots of performance on the Navon Similarity Judgement task for all participant groups.

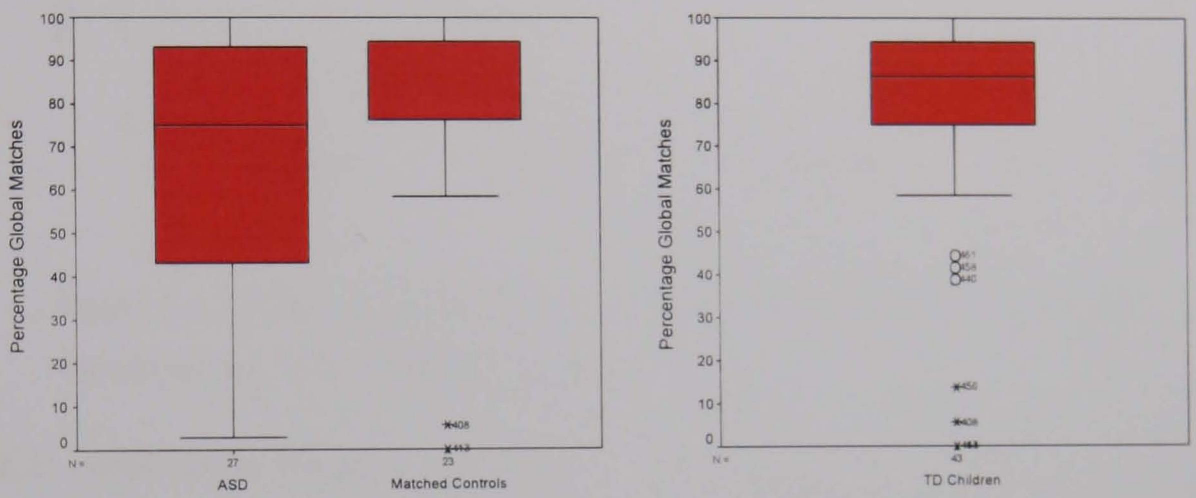


Figure 6–15. Percentage Global Matches on the Navon Similarity Judgement Task by Children with ASD, Matched Controls, and TD Children.

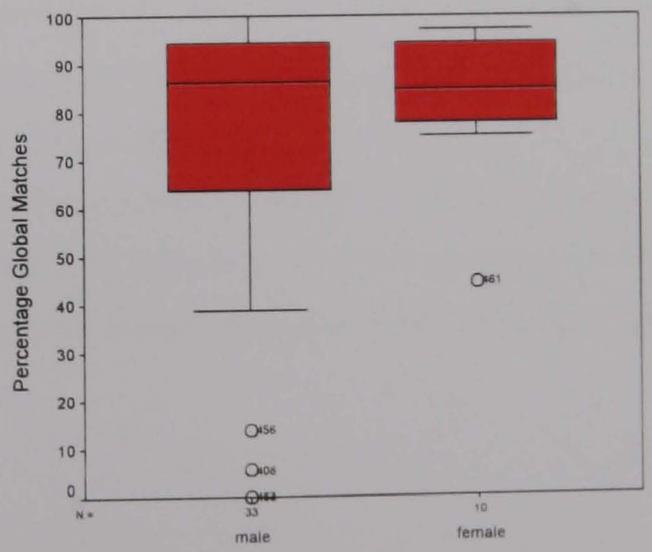


Figure 6–16. Percentage Global Matches on the Navon Similarity Judgement Task by Males and Females within the Group of TD Children.

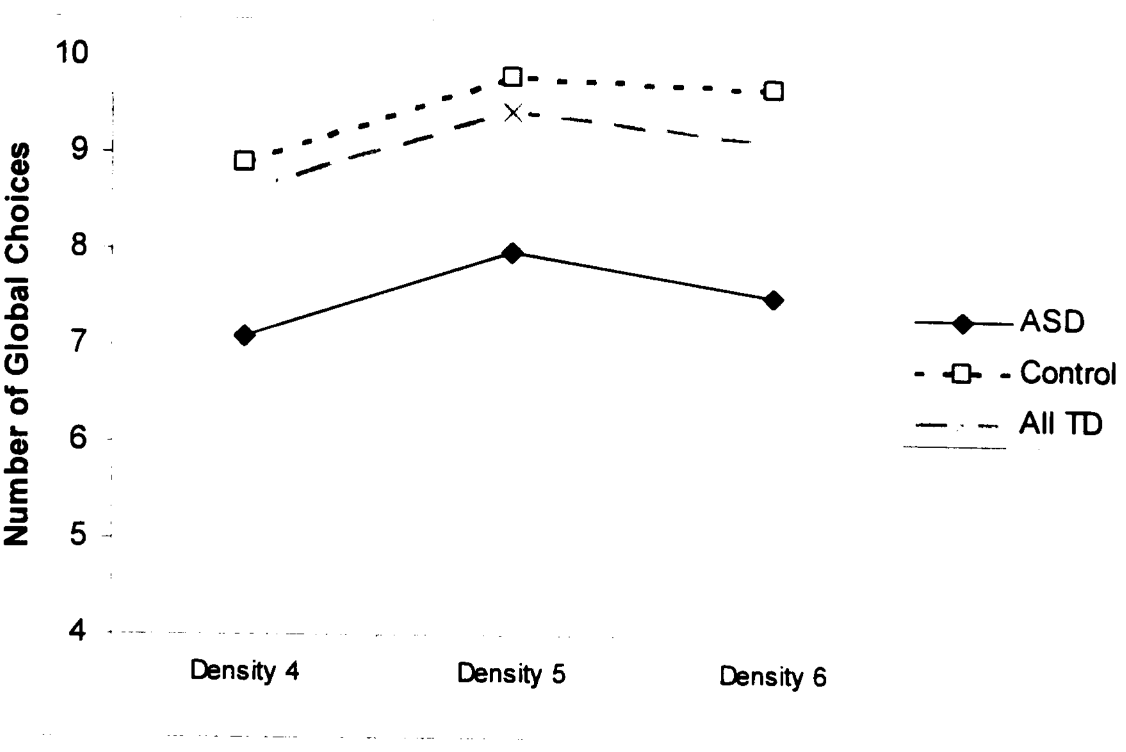


Figure 6–17. Number of Global Choices (max=10) by Density Level and by Group on the Navon Similarity Judgement Task.

6.6.2 ASD versus Matched Controls:

Means and standard deviations of Navon-type task performance by group are summarised in Table 6-18. When attempting to analyse percentage of global responses across the entire Navon-type task utilising parametric methods, Levene's Test of Equality of Error Variances was failed (F=5.52, *p*=.02); therefore, Mann-Whitney was used to assess potential group differences in ranking of scores. This difference failed to reach significance, though ASD children more often responded locally than did matched control (and TD) children.

Because these data were not normally distributed, interactions between density type and group could not be explored. However, examining Figure 6-17 revealed that the pattern of performance across density levels was strikingly similar across the groups.

Table 6–18. Percentage of Global Matches on the Navon-type task Amongst Children with ASD, Matched Controls, and TD Children: Mean (SD).

	ASD (n=27)	Matched Controls (n=23)	TD Children (n=43)	Z	*p*	Cohen's *d*
% Global Matches	62.96 (35.03)	79.09 (26.93)	76.09 (27.73)	1.62▲	.10	0.52

▲Z value from Mann-Whitney

With Outliers Removed:

Two outliers were removed from the matched control group (n=21). Again, when attempting to analyse percentage of global responses on the Navon-type task utilising parametric methods, Levene's Test of Equality of Error Variances was failed (F=27.04, *p*<0.001); therefore, Mann-Whitney was used to assess differences in ranking of scores. Percentage of global responses was significantly higher (Z=2.23, *p*=0.03, *d*=0.89) for the matched control (M=86.35 ± 12.62) than the ASD group (M=62.96 ± 35.03), indicating a favoured local response amongst the individuals with ASD.

Again, the non-normal distribution of scores prevented the examination of interactions between group and density level, but the pattern of results remained similar to those presented in Figure 6-17.

6.6.3 Gender Differences in Navon Similarity Judgement Task Performance

The Navon-type task was one of the last tasks in the battery and as such, was one of the first to be excluded in cases of time constraint; therefore, only 43 of the TD children received the task. To this end, gender differences in performance were not examined because only 10 of the 43 TD children were female, providing limited power for meaningful analyses. Though females (M=83 ± 15) tended to respond more globally in their matches to the target stimuli than did males (M=74 ± 30), this difference failed to reach statistical significance (F=0.69, *p*=.41, *d*=0.38).

6.6.4 Relationship of Age and IQ with Percentage of Global Responses on the Navon Similarity Judgement Task:

Spearman correlations were run (with and without outliers included) in order to examine the relationship between global categorisation of Navon-type stimuli and age and IQ across the three participant groups (see Table 6-19). Percent global responses across all trials did not correlate significantly with age or IQ in the TD children or matched control group, whether or not outliers were included. However, amongst the children with ASD, vocabulary score was positively correlated with percentage of global responses on this task. Indeed, when comparing this correlation to those found in the group of TD children with and without outliers included, a significant difference was noted (outliers included: $z_{r1r2}=2.46$, $p=.01$; outliers excluded: $z_{r1r2}=2.21$, $p=.03$). The difference in the same correlations between children with ASD and matched controls was not as clear cut; retaining outliers resulted in a significant difference ($z_{r1r2}=1.93$, $p=.05$), whereas removing outliers provided nonsignificant results ($z_{r1r2}=1.22$, $p=0.22$). Nevertheless, it remains unique for individuals with ASD that verbal ability relates to processing this task in a global fashion.

Table 6–19. Correlations between Percentage of Global Responses on the Navon-type Task and Age and IQ Amongst ASD Children, Matched Controls, and TD Children with and without Outliers Included (Results after the Removal of Outliers Presented in Parentheses).

Navon % Global Responses	% Glob Resp in ASD‡ (N=27)	% Glob Resp in Matched Controls‡ (N=23; N=21)	% Glob Resp in TD Children‡ (N=43)
Age	-.13	.15 (.03)	.22 (.20)
Vocab	.40*	-.16 (.05)	-.21 (-.16)
Block Design	.16	.21 (.34)	.01 (-.06)
FSIQ	.32	-.06 (.14)	-.07 (-.08)

*$p<.05$

‡-Spearman's rho utilised

6.7 The Sentence Completion Task

- Individuals with ASD were predicted to more frequently respond locally to sentence stems. Even when responding in a global fashion, individuals with ASD were predicted to take longer to respond in this way, since local responses are predicted to be their default approach to the task.

The two primary indices of performance were the number of frank local completions, such as "In the sea, there are fish and....*chips*"; and the total error score, which incorporated not only frank local completions (scored as two points), but also hesitations of 10 seconds or more (scored as one point) when trying to complete the sentence stem. Because of concerns over restricted range of scores, data were also categorised by performance. Since frank local completions were considered most representative of local processing, groups were split according to whether or not two or more frank local completions were provided.

6.7.1 Distribution of Scores:

Figures 6-18 and 6-19 present box plots of performance on the sentence completion task for all participant groups.

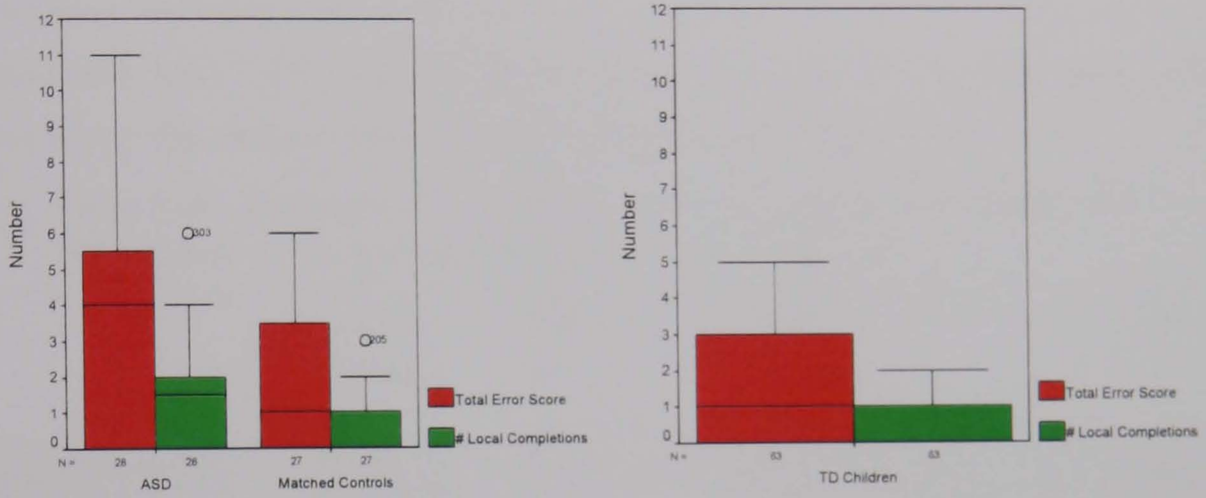


Figure 6–18. Box Plot of Sentence Completion Error Scores Amongst Children with ASD, Matched Controls, and TD Children.

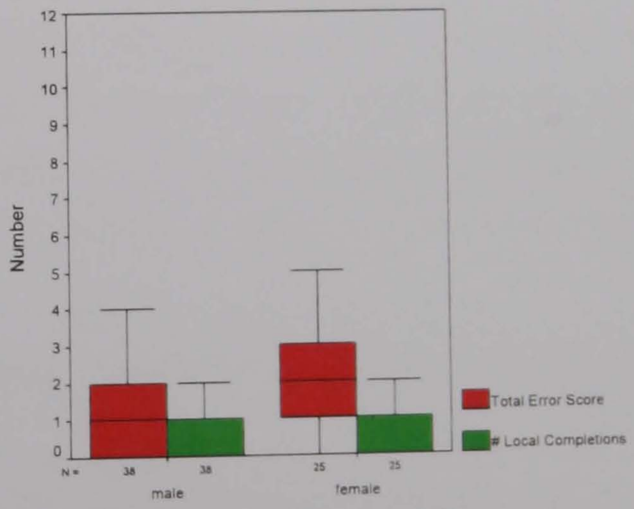


Figure 6–19. Sentence Completion Error Scores by Gender Amongst TD Children.

6.7.2 ASD versus Matched Controls:

A one-way ANOVA showed that individuals with ASD and matched controls differed in their total error score and the number of local completions they provided (see Table 6-20). Individuals with ASD had a significantly higher total error score indicating a more local approach to completing the sentence stems. Because a parametric test was inappropriate (due to a failed Levene's Test of Equality of Error Variances: F=5.10, *p*=.03), a nonparametric Mann-Whitney test was run in order to assess the between group difference in score rankings for number of local completions provided. Again, indicating a more local orientation, individuals with ASD displayed a significantly greater number of local completions than did matched controls. A Pearson chi-square test was run to examine the between group differences in the number of individuals who gave two or more local completions. Consistent with predictions, significantly more (χ^2= 4.58, *p*=.05) individuals with ASD (n=14, 50%) gave local associates to the sentence stems than did matched controls (n=6, 22%).

Table 6–20. Performance by Children with ASD, Matched Controls, and TD Children on the Sentence Completion Task: Mean (SD).

	ASD (n=28)	Matched Controls (n=27)	TD Children (n=63)	F/Z	*p*	Cohen's *d*
Total Error Score	3.64 (3.09)	1.96 (2.23)	1.59 (1.51)	5.31	.02	0.62
# of Local Completions	1.57 (1.40)	0.70 (0.91)	0.46 (0.64)	2.28▲	.02	0.74

▲Z value from Mann Whitney

With Outliers Removed:

The number of local completions variable contained one outlier for each of the groups. After removal of these two outliers, individuals with ASD (n=27, M=1.41 ± 1.28) remained significantly more locally oriented (Z=2.36, *p*=.02, *d*=0.74), as indicated by the number of local associates provided, than the matched controls (n=26, M=0.62 ± 0.80).

6.7.3 Gender Differences in Sentence Completion Performance:

Surprisingly, as can be seen in Table 6-21, females were more locally oriented when completing sentence stems as evidenced by their generally higher error score; however, the difference in number of local completions just missed reaching the significance threshold.

Because the frequency of the number of males and females who provided at least two local completions to the sentence stems fell below the five count minimum required for use of Chi-square, Fisher's Exact Test was used to assess group differences. There was no significant difference in the number of males (n=2; 5%) and females (n=3; 12%) who provided two or more local completions (*p*=.38).

Table 6–21. Total Error Score and Number of Local Completions on the Sentence Completion Task for TD Males and Females: Mean (SD).

	Males (n=38)	Females (n=25)	F/Z	*p*	Cohen's *d*
Total Error Score	1.24 (1.38)	2.12 (1.56)	5.54	.02	0.60
# of Local Completions	0.34 (0.58)	0.64 (0.70)	1.85▲	.06	0.47

▲Z value from Mann Whitney

6.7.4 Relationship of Age and IQ with Sentence Completion Performance:

Correlations between the total error score and age and IQ variables were calculated across the three groups using Spearman's rho. However, the categorical nature and restricted range of scores inherent to calculating the number of local completions warranted caution in the use of correlations. So, as an additional index of these potential relationships, differences in age and IQ between those who made two or more local completions versus those who did not, was examined within each of the participant groups.

Spearman correlations were run to examine the relationship between the total error score on the sentence completion task and age and IQ across the three participant groups (see Table 6-22). For the matched control group, total error score was negatively correlated with indices of IQ; however, this was not the case for the sample of TD children (with the ASD falling between the two), which indicates that the lower IQ subsample of the matched control group is likely carrying this relationship. Indeed, if the six lowest IQ scorers (FSIQ≤72) from the matched control group were removed and the Spearman correlation between FSIQ and total error score was rerun, the correlation drops below significance (rho=-0.30, *p*=.17). Confirming that this finding was not due to reducing the range of IQ scores, removal of the top six IQ scores from the matched control group maintained the significant correlation between FSIQ and total error score (rho=-.61, *p*=.004).

Supporting the correlational findings, FSIQ amongst the children with ASD did not differ significantly (F=1.02, *p*=.32, *d*=0.38) between those who provided two or more local completions (n=14; M=88.86 ± 21.59) and those who gave one or no local completions (M=97.57 ± 24.00). Similar findings were noted amongst the TD children with no difference in FSIQ between local responders (n=5; M=108.20 ± 7.66) and global responders (M=107.58 ± 12.28; F=0.01, *p*=.91, *d*=0.06). However, the matched controls who provided two or more local completions (n=6; M=71.33 ± 22.50) scored significantly lower (F=18.18, p=.0002, d=1.70) on the measure of FSIQ than those who gave one or no local completions (M=103.19 ± 14.11), in line with the correlations reported in Table 6-22.

Table 6–22. Spearman Correlations between Sentence Completion Performance and Age and IQ Amongst Children with ASD, Matched Controls, and TD Children.

Total Error Score	ASD (N=28)	Matched Controls (N=27)	TD Children (N=63)
Age	-.11	.08	-.20
Vocab	-.30	-.53**	-.19
Block Design	-.33	-.53**	-.01
FSIQ	-.37	-.57**	-.11

**p<.01

6.8 Time Perception

- Three domains of time perception were assessed: time estimation, time production, and time reproduction. Individuals with ASD were predicted to show comparable performance to controls in terms of time estimation and time production. However, individuals with ASD were expected to demonstrate (relatively) better time reproduction performance than matched controls.

Time perception variables were calculated by taking the difference between the actual time passage and the time given by the participant. These difference scores were then converted into ratios, based on the amount of time that actually passed. Therefore, a difference score of zero would result in a ratio of one, an overestimate would result in a ratio greater than one, and an underestimate would result in a ratio of less than one. To supplement these ratios, each individual was categorised according to whether they overestimated (ratio>1) or underestimated (ratio<1) across each of the time perception tasks. This categorisation, completed on only the summary ratios, provided an index of the predominant style of response to each of the time perception tasks.

6.8.1 Distribution of Scores:

Figures 6-20 and 6-21 present box plots of performance on the time perception tasks for all participant groups.

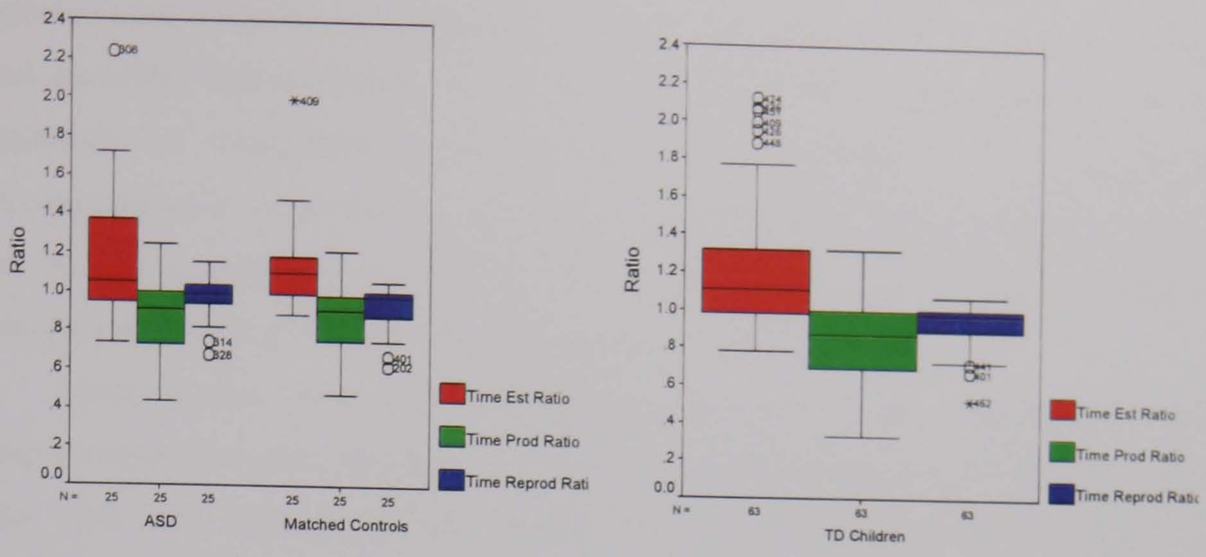


Figure 6–20. Time Perception Performance Amongst Children with ASD, Matched Controls, and TD Children.

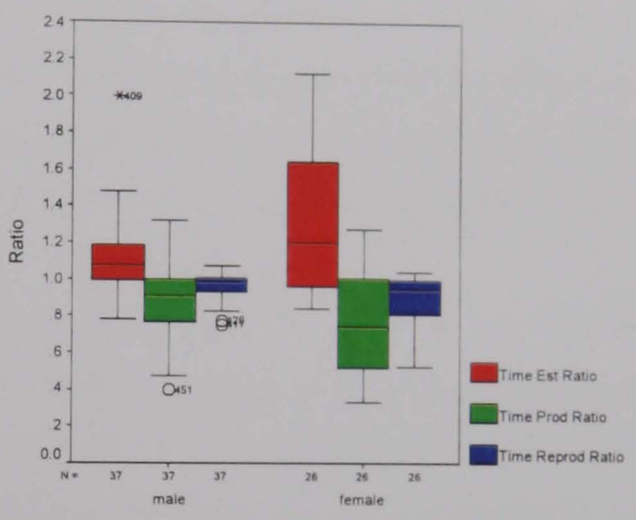


Figure 6–21. Time Perception Performance by Gender Amongst TD Children.

6.8.2 ASD versus Matched Controls:

A three-way ANOVA was run in order to examine interactions of performance on the time perception tasks by duration and by group. See Table 6-23 for means and standard deviations for overall ratio scores and Figures 6-22, 6-23, and 6-24 for ratio scores by task type and duration. Mauchly's test of sphericity was violated (*p*<.001); therefore, *p* values reported are those involving a Greenhouse-Geisser correction. Within subject comparisons revealed a significant interaction between task type and duration (F=6.64, *p*<.001), but nonsignificant interactions between task type and group (F=0.28, *p*=.65) and between task type, group, and duration (F=0.51, *p*=.71). As can be seen in Table 6-23, for both groups, the time estimation task was generally overestimated, while the time production and time reproduction tasks, to a lesser extent, were generally underestimated. Duration had a particularly marked influence on the magnitude of overestimation in the time estimation task, with a decreasing overestimation as the duration increased (see Figure 6-22), whereas, time production and (to a lesser extent for the ASD group) time reproduction showed more consistent performance across the durations (see Figures 6-23 and 6-24).

Since a ratio score of one is the ideal score on the time perception tasks, one-sample t-tests were run separately for ASDs and matched controls to assess whether their total time estimation, time production, and time reproduction ratios were significantly different from this ideal score. Both individuals with ASD and matched controls had time estimation (ASD: t=2.42, *p*=.02; controls: t=2.77, *p*=.01) and time production (ASD: t=3.46, *p*=.002; controls: t=3.36, *p*=.003) ratio scores that differed significantly from one. However, the pattern of results for each group differed on the time reproduction task. Whereas time reproduction performance amongst matched controls was consistent with the other two time perception indices in being significantly different from one (t=3.60, *p*=.001), it was not significantly different from one for the individuals with ASD (t=1.59, *p*=.13).

Pearson chi-square tests were run in order to compare the proportion of children with ASD and matched controls who over or underestimated time passage on the three time perception tasks. No one scored a flawless ratio of one on the summary proportional RT variable from the time estimation task; however, two matched controls and two children with ASD scored a perfect one on the time production task, and three matched controls and two children with ASD scored a ratio of one on the time reproduction task. Individuals with ratio scores of one were omitted from these analyses, so that each participant could be accurately categorised as over or underestimating on each of the three tasks. Results revealed that a similar proportion of children with ASD and matched controls overestimated time passage on the time estimation (ASD=68%, matched controls=68%; χ^2=0, *p*=1), time production (ASD=26%, matched controls=17%; χ^2=0.51, *p*=.48), and time reproduction (ASD=35%, matched controls=19%; χ^2=1.37, *p*=.24) tasks.

Table 6–23. Time Perception Ratio Scores for ASD, Matched Control, and TD Children: Mean (SD).

	ASD (n=25)	Matched Controls (n=25)	TD Children (n=63)	F	*p*	Cohen's *d*
Time Estimation All	1.17 (0.35)	1.13 (0.24)	1.21 (0.33)	0.22	.64	0.13
Time Production All	0.85 (0.21)	0.87 (0.19)	0.84 (0.23)	0.13	.72	0.10
Time Reproduction All	0.97 (0.11)	0.92 (0.11)	0.94 (0.11)	2.37	.13	0.45

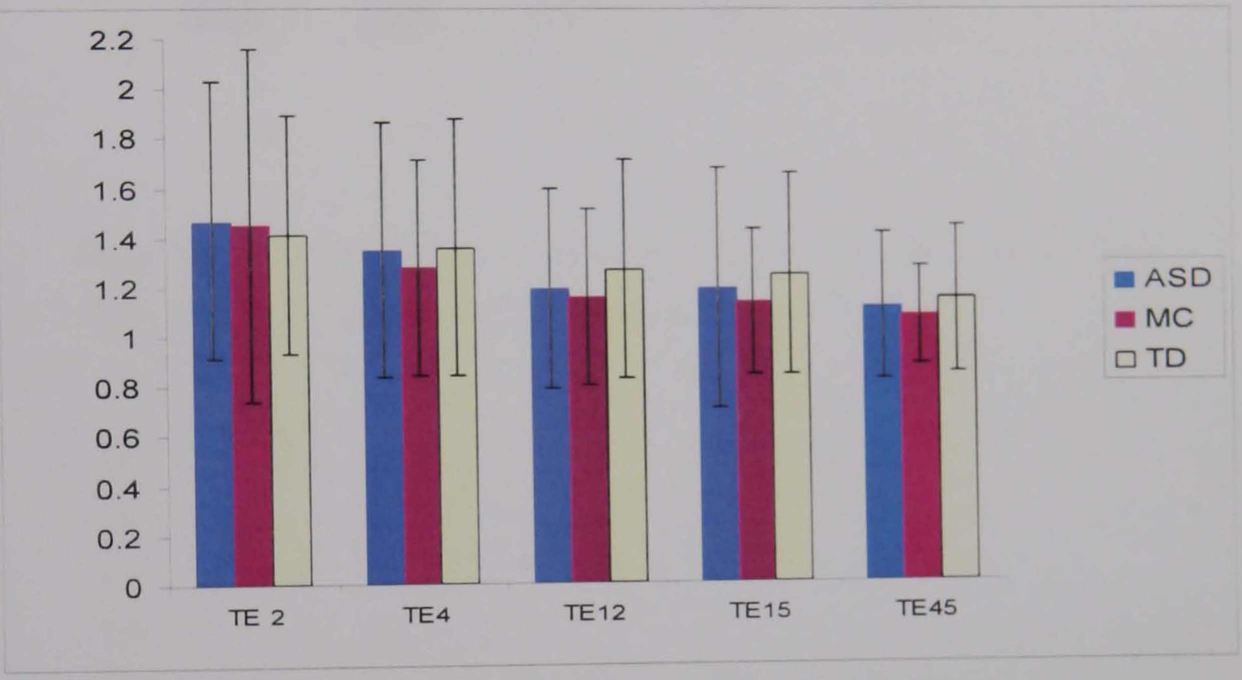


Figure 6–22. Time Estimation Ratios by Duration Amongst Children with ASD, Matched Controls, and TD Children.

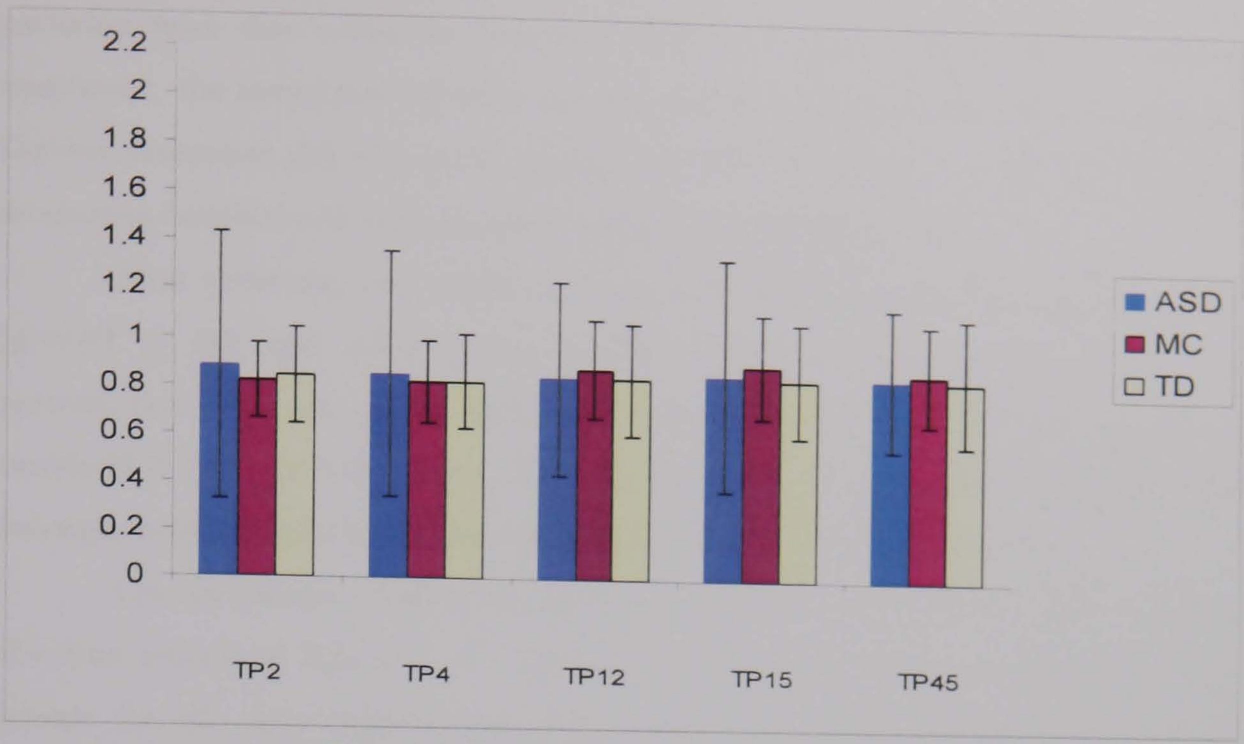


Figure 6–23. Time Production Ratios by Duration Amongst Children with ASD, Matched Controls, and TD Children.

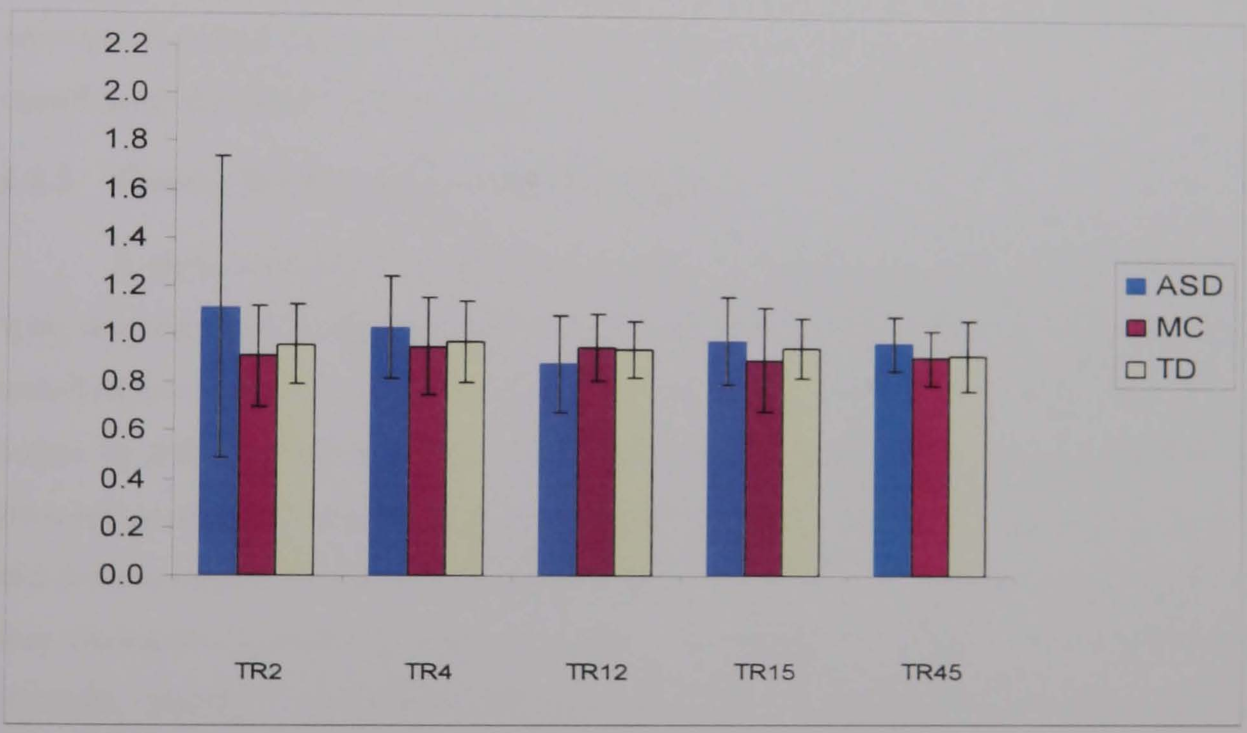


Figure 6–24. Time Reproduction Ratios by Duration Amongst Children with ASD, Matched Controls, and TD Children.

With Outliers Removed:

Another three-way ANOVA was run after removing several outliers from each of the time perception tasks by duration. Since this is an omnibus analysis, it takes only one outlying data point from any one condition to exclude that individual from the analysis. Therefore, a total of nine individuals with ASD and 11 matched controls were excluded from this follow-up three-way ANOVA. Nevertheless, results remained consistent: the interaction between time perception task and group after Greenhouse-Geisser correction did not reach significance (F=1.41, *p*=.25) nor did the three-way interaction between task type, duration, and group (F=1.48, *p*=.22).

After removing two outlying scores each from the matched control (n=23, M=0.94 ± .08) and ASD groups (n=23, M=0.99 ± .08) for the overall time reproduction ratio, the group differences just reached the conventional significance threshold (F=3.94, *p*=.05). These results indicate better time reproduction performance amongst individuals with ASD as compared to that for matched controls.

The one-sample t-tests were run again after the removal of one ASD outlier for the time estimation task and two outliers each from the ASD and matched control groups for the time reproduction task. Similar to results presented above, both individuals with ASD and matched controls had time estimation (ASD: t=2.23, *p*=.04; controls: t=2.98, *p*=.006) ratio scores that differed significantly from one. Patterns of performance remained different between groups with time reproduction performance amongst matched controls significantly different from one (t=3.37, *p*=.003) but not significantly different from one for the individuals with ASD (t=0.73, *p*=.47).

6.8.3 Gender Differences in Time Perception:

A three-way ANOVA was run in order to examine interactions between task type, duration, and gender amongst the TD individuals. See Table 6-24 for means and standard deviations by overall task ratio score and Figures 6-25, 6-26 and 6-26 for ratio scores by task type and duration. After Greenhouse-Geisser correction, the interaction between gender and time perception task type remained significant (F=5.84, *p*=.02) as did the interaction between duration and gender (F=5.84, *p*=.002); however, the three way interaction between gender, task type, and duration did not reach significance (F=0.28, *p*=.91). Follow-up one-way comparisons revealed that males scored significantly (*p*<.05) better time estimation ratios across all five durations and demonstrated a better time estimation summary score. Ratio scores for time production were not significantly (*p*>.05) different between males and females. The summary time reproduction ratio score was significantly higher for males than for females (F=5.71, *p*=.02); however, examination of each duration revealed only the 45 second condition as significantly different (F=10.14, *p*=.002) by gender and therefore primarily responsible for the summary score difference.

Just as for individuals with ASD and matched controls, one-sample t-tests were run separately for males and females in order to examine whether the ratio scores were significantly different from one. Both males and females had ratio scores that were significantly different from one on the time estimation (males: t=3.22, *p*=.003; females: t=4.01, *p*=.0005), time production (males: t=3.75, *p*=.001; females: t=4.02, *p*=.0005), and time reproduction (males: t=3.28, *p*=.002; females: t=3.85, *p*=.001) tasks.

As above, Pearson chi-square tests were run in order to compare the proportion of males versus females who over or underestimated time passage on the three time perception tasks. Results revealed that a similar proportion of males and females overestimated time passage on the time estimation (Males=69%, Females=69%; $\chi^2=0$, *p*=1), time production (Males=18%, Females=18%; $\chi^2=0$, *p*=1), and time reproduction (Males=29%, Females=19%; $\chi^2=0.67$, *p*=.42) tasks.

Table 6–24. Gender Differences in Time Perception Performance: Mean (SD).

	Males (n=37)	Females (n=26)	F	*p*	Cohen's *d*
Time Estimation All	1.11 (0.22)	1.33 (0.43)	7.25	.01	0.64
Time Production All	0.88 (0.20)	0.79 (0.27)	2.54	.12	0.38
Time Reproduction All	0.96 (0.07)	0.90 (0.13)	5.71	.02	0.57

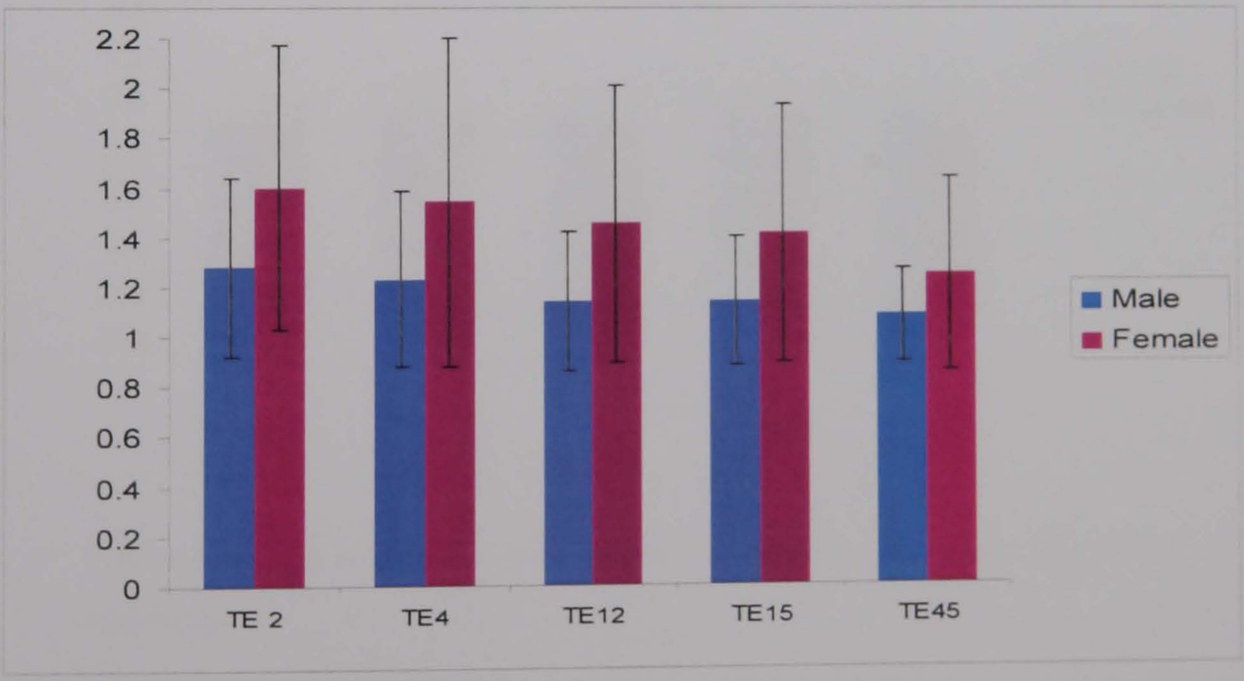


Figure 6–25. Time Estimation Ratios by Duration Amongst TD Males and Females.

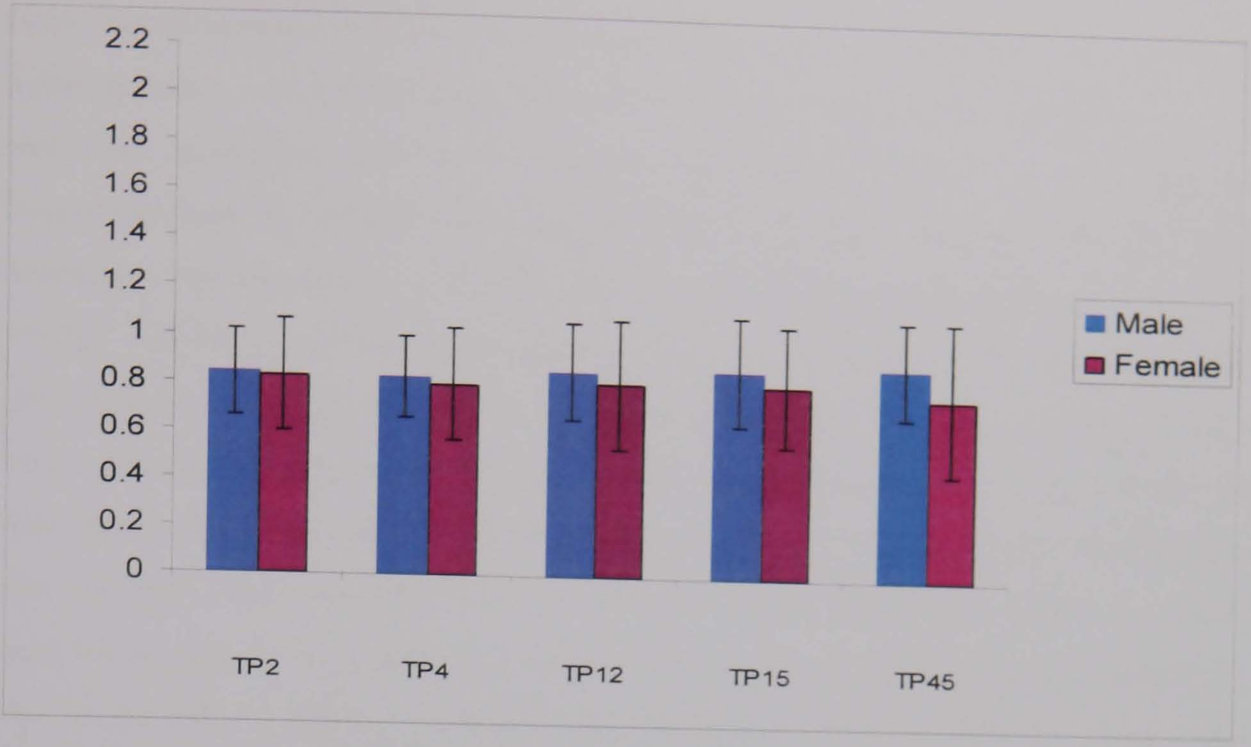


Figure 6–26. Time Production Ratios by Duration Amongst TD Males and Females.

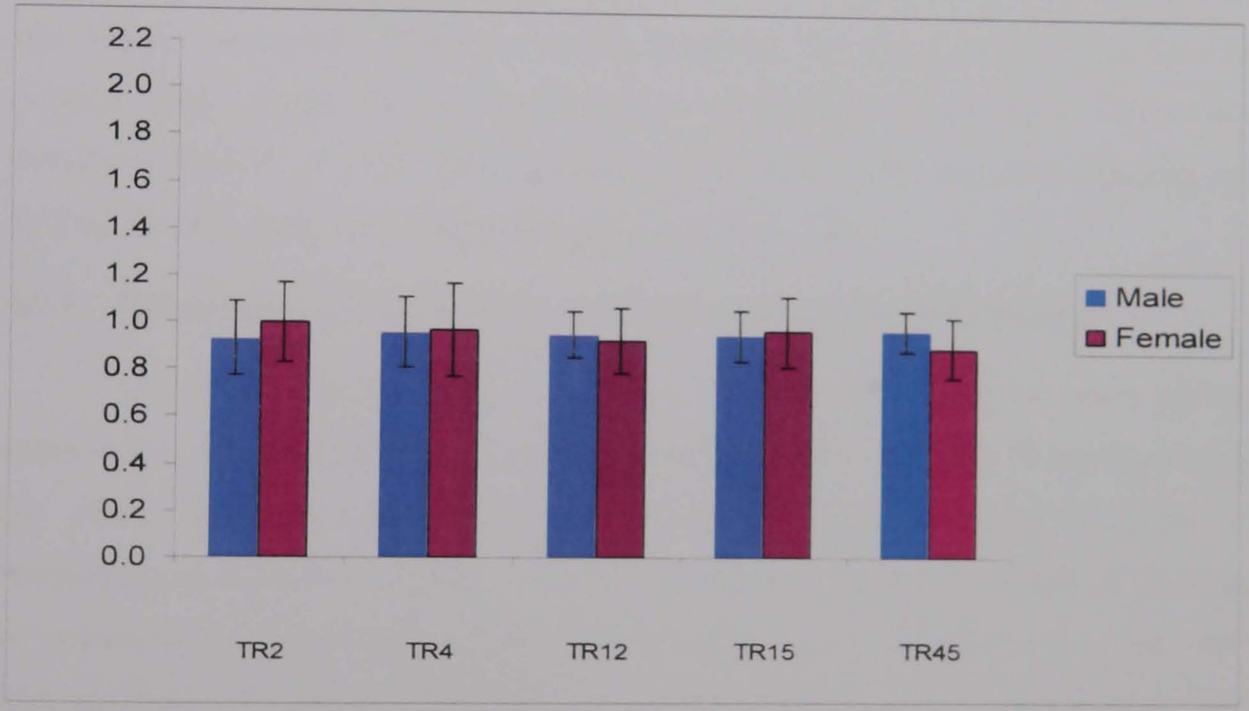


Figure 6–27. Time Reproduction Ratios by Duration Amongst TD Males and Females.

With Outliers Removed:

Another three-way ANOVA was run after removing several outliers from each of the time perception tasks by duration. Again, since this is an omnibus analysis, it takes only one outlying score from any one condition to exclude that data point from the analysis. Therefore, data from a total of 10 males and seven females were excluded from this three-way ANOVA. Results remained consistent with those that included outlying scores. After Greenhouse-Geisser correction, the interaction between gender and time perception task type remained significant (F=5.96, *p*=.02) as did the interaction between duration and gender (F=5.77, *p*=.001); however, the three way interaction between gender, task type, and duration did not reach significance (F=1.09, *p*=.37). Follow-up one-way comparisons revealed again that males scored significantly (*p*<.05) better time estimation ratios across all five durations and demonstrated a better time estimation summary score. Corroborating results reported above, ratio scores for time production were not significantly (*p*>.05) different between males and females. The summary time reproduction ratio score was again significantly higher for males than for females (F=8.72, *p*=.004); however, examination of each duration revealed only the 45 second condition as significantly different (F=8.76, *p*=.004) by gender and therefore primarily responsible for the summary score difference.

Of the summary ratio scores calculated for each of the time perception tasks, only one male outlier each for time estimation and time production and two for time reproduction occurred. When re-running separately for males (since there were no outlying female scores) the one-sample t-tests, results remained the same. Males' time estimation (t=3.39, *p*=.002), time production (t=3.56, *p*=.001), and time reproduction (t=2.96, *p*=.006) ratio scores differed significantly from one.

6.8.4 Relationship of Age and IQ with Time Perception Performance:

To reiterate, the time perception ratio scores are computed so that a perfect score is one and any departure in either direction indicates over or underestimation on the tasks. Utilising the ratio scores in correlations would create difficulties in interpretation; therefore, a simple, alternative metric was computed. A difference score of requested duration versus the duration provided by the participant was computed. The absolute value of this difference, with zero indicating no discrepancy, was then utilised in correlational analyses presented below.

Pearson correlations were run to examine the relationship between time perception and age and IQ across the three participant groups (see Tables 6-25, 6-26, and 6-27). Time production scores were found to be significantly age-related in the group of TD children, as were time estimation abilities, but only when outliers were included. After outliers were removed, time reproduction was significantly related with age in the group of matched controls. In terms of relationships to IQ measures, time estimation ability was negatively correlated with the vocabulary score in the ASD group (significantly so, only with outliers included), but positively correlated, after outliers were removed, with the vocabulary score in the group of TD children. The correlations between time estimation performance and vocabulary score were significantly different for the ASD and TD children groups with outliers both included (z_{r1r2}=2.24, p=.03) and excluded (z_{r1r2}=2.17, p=.03).

Table 6–25. Correlations between Time Perception and Age and IQ Amongst ASD Children with and without Outliers Included (Results after the Removal of Outliers Presented in Parentheses).

ASD Only	Time Estimation (n=25; 24)	Time Production (n=25)	Time Reproduction (n=25; 23)
Age	-.18 (-.37)	-.37	.17 (-.08)
Vocab	-.42* (-.17)	-.23	-.39 (-.42*)
Block Design	-.36 (-.17)	-.11	-.19 (-.18)
FSIQ	-.42* (-.18)	-.18	-.31 (-.32)

*p<.05

Table 6–26. Correlations between Time Perception and Age and IQ Amongst Matched Controls with and without Outliers Included (Results after the Removal of Outliers Presented in Parentheses).

Matched Controls	Time Estimation (n=25; 24)	Time Production (n=25)	Time Reproduction (n=25; 23)
Age	-.15 (.12)	.06	.29 (.45*)
Vocab	.14 (.26)	.11	-.01 (.03)
Block Design	-.13 (-.22)	-.23	-.37 (-.04)
FSIQ	.01 (.04)	-.06	-.20 (.01)

*p<.05

Table 6–27. Correlations between Time Perception and Age and IQ Amongst TD Children with and without Outliers Included (Results after the Removal of Outliers Presented in Parentheses).

All TD Children	Time Estimation (n=63; 57)	Time Production (n=63)	Time Reproduction (n=63; 60)
Age	-.29* (-.10)	-.31*	-.003 (.07)
Vocab	.11 (.37**)	-.06	.14 (-.01)
Block Design	-.17 (-.18)	-.09	.02 (.01)
FSIQ	-.06 (.10)	-.10	.09 (-.001)

*p<.05, **p<.01

6.9 Inspection Time

- IT was predicted to be shorter, representing faster processing speed, for individuals with ASD than the age and IQ matched control group.

Of the 26 ASD and the 26 matched control participants originally administered the IT task, one from each participant group had their data deemed invalid based on a variance score computed automatically in the IT program. The variance score indicates whether the IT score for each individual was being overly influenced by performance during early long exposures, which was the case for these two participants. Additionally, two of the ASD participants' data were lost through computer malfunction.

6.9.1 Distribution of Scores:

Figures 6-28 and 6-29 present box plots of IT performance for all participant groups.

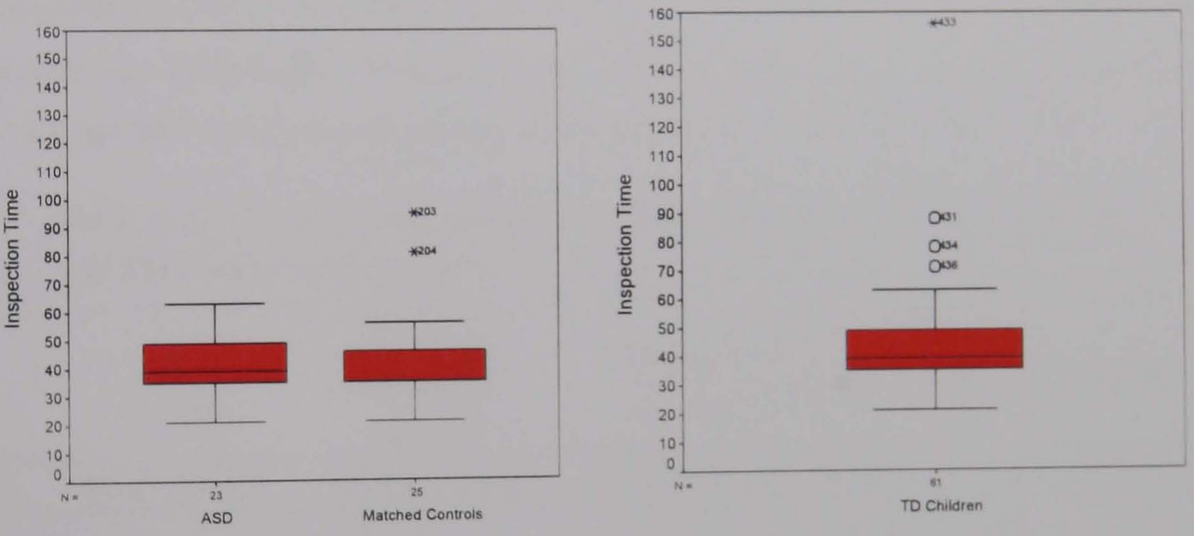


Figure 6–28. IT (in milliseconds) Amongst Children with ASD, Matched Controls, and TD Children.

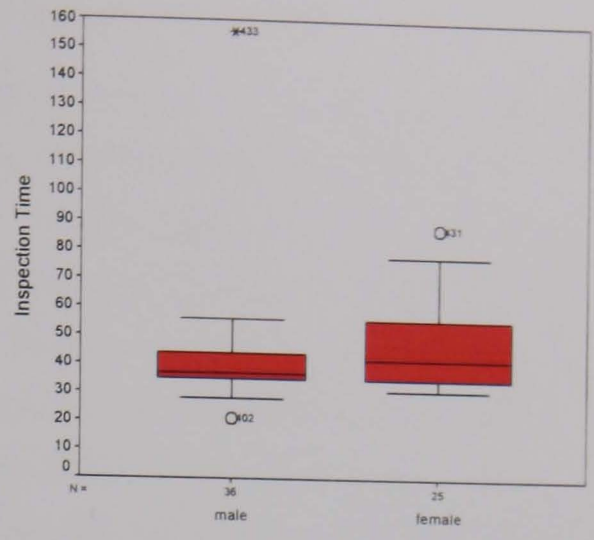


Figure 6–29. IT (in milliseconds) by Gender Amongst TD Children.

6.9.2 ASD versus Matched Controls:

A one-way ANOVA was run in order to examine potential group differences in IT performance between children with ASD and matched controls. Children with ASD demonstrated similar processing efficiency, as measured by IT, to age and IQ matched controls (see Table 6-28). After removing two outliers from the matched control group (n=23; M=38.7 ± 9.5), results remained nonsignificant (F=0.89; *p*=.35; *d*=0.28).

Table 6–28. IT (in milliseconds) for Children with ASD, Matched Controls, and TD Children: Mean (SD).

	ASD (n=23)	Matched Controls (n=25)	TD Children (n=61)	F	*p*	Cohen's *d*
IT	41.43 (10.19)	42.64 (16.54)	44.42 (19.14)	0.09	.77	0.09

6.9.3 Gender Differences in IT:

Amongst the sample of TD children, boys (n=36, M=41.92 ± 21.14) and girls (n=24, M=48.17 ± 15.31) did not differ significantly in their IT performance (F=1.55, *p*=0.22, *d*=0.34) if outliers were retained. However, after removing two outliers from the sample of males and one outlier from the sample of females, a significant group difference emerged (F=7.00, *p*=0.01, *d*=0.68), indicating greater processing efficiency amongst boys (n=34, M=39.18 ± 7.67) than girls (n=23, M=46.43 ± 13.03). Because of the relevance of IQ to IT, it is important to reiterate that male (M=109.91 ± 11.84) and female (M=106.83 ± 10.65) subgroups minus outliers did not differ (F=1.01, *p*=.32, *d*=0.27) on IQ.

6.9.4 Relationship of Age and IQ with IT:

Pearson correlations were run to examine the relationship between IT and age and IQ across the three participant groups (see Table 6-29). As predicted, there was no significant relationship between age and IT in any of the groups. Significant correlations between all three IQ variables (i.e., vocabulary, Block Design, and total IQ estimate) and IT were limited to matched controls. However, when examining the relationship between IQ and IT in the sample of TD children, it becomes clear that the relationship is carried by Block Design performance. It can then be inferred that amongst the matched controls the children with MLD showed a strong relationship between vocabulary score and IT (n=7, r=-.57), unlike TD children (n=18, r=.14). Unique to the ASD group was the lack of relationship between IT and Block Design performance. Indeed, even with the small sample sizes reported here, the correlations between Block Design performance and IT were significantly different for the ASD and matched control groups (z_{r1r2}=2.32, *p*=.02) and for the ASD and TD children groups (z_{r1r2}=2.01, *p*=.04).

Table 6–29. Correlations between IT and Age and IQ Amongst ASD Children, Matched Controls, and TD Children (Results after the Removal of Outliers Presented in Parentheses).

IT	IT in ASD (N=23)	IT in Matched Controls (N=25; 23)	IT in TD Children (N=61; 57)
Age	.01	.17 (.20)	-.22 (-.21)
Vocab	-.29	-.56** (-.21)	.09 (.10)
Block Design	.13	-.53** (-.38)	-.37** (-.32*)
FSIQ	-.08	-.59** (-.33)	-.21 (-.17)

**p*<.05, ***p*<.01

6.10 Relationship Amongst Central Coherence, IT, Implicit Learning, and Time Perception Tasks

In order to better understand how performance on tasks of central coherence, IT, implicit learning, and time perception interrelate and possibly provide clues as to what processes may be underlying task success and failure for each group, three separate correlation matrices are presented below. Parametric correlational results using Pearson's r are presented in the following tables. In cases where Spearman's rho/nonparametric correlations are required because of violations of assumptions underlying parametric statistics, these scores are presented in parentheses alongside the parametric results. Furthermore, a partial correlation is also presented wherein both vocabulary score, as a proxy for verbal IQ, and age were treated as nuisance variables and partialled out. Vocabulary score was utilised instead of Block Design or the estimated FSIQ (which is computed using the Block Design score), because Block Design performance (as an index of central coherence) would be theoretically related to performance on a number of the experimental measures. Results are presented with outliers included, and correlations where the significance changed (either becoming significant or no longer significant) with the exclusion of outliers are indicated with a superscript symbol (‡). Though significant results at both the $p<.05$ and $p<.01$ levels are noted, discussion centres primarily on the more robust $p<.01$ results, given the large number of correlations conducted. The experimental task indices were chosen according to which maximally discriminated children with ASD from matched controls. When an index for an experimental task did not distinguish these groups, then the summary variable (i.e., difference score for the time perception tasks, IT for processing speed, proportional RT savings from the first to the second halves of the implicit learning task, percentage of global matches on the Navon-type task, and A' for im/possible figures categorisation) for that task was utilised in the correlation matrices. This resulted in 10 indices correlated with one another. Tables 6-30, 6-31, and 6-32 show the specific results.

6.10.1 Hypotheses:

Because central coherence has been conceptualised as a cross-modal, unitary construct (Frith, 1989), it was predicted that performance on measures designed to assess central coherence (i.e., EFT, sentence completion, im/possible figures categorisation, Navon-type task, and un/segmented Block Design) would correlate with one another, though the limited range of sentence completion error scores, particularly within the comparison groups, makes significant correlations with this task unlikely.

Because time perception was also conceptualised as a unitary construct, significant positive correlations in performance were expected between time estimation, production, and reproduction.

Amongst TD children and matched controls, IT scores were predicted to vary with performance on other g-loading tasks; in this case, EFT and im/possible figures categorisation. More specifically, IT was expected to correlate positively with average time spent on the standard EFT items, since in both cases higher scores represent poorer performance; while it should negatively correlate with im/possible figures categorisation since higher A' scores reflect better performance. However, because EFT performance reflects (IQ-independent) WCC amongst individuals with ASD, no such significant correlation was expected for this group.

Because implicit learning is theoretically independent of IQ, performance on this task for all groups was not expected to be correlated significantly with g-loading dimensions, such as those listed above.

6.10.2 Results:

All correlations across the three participant groups are presented in Tables 6-30, 6-31, and 6-32. There was some evidence to support the hypothesis that tasks purporting to tap central coherence would correlate with one another. Both TD kids and matched controls (only after age and vocabulary score were partialled out) demonstrated positive correlations between average time on standard EFT items and percentage RT gain on the un/segmented Block Design task and negative correlations between average time on standard EFT items and A' score on the im/possible figures categorisation task. These correlations were not significant in the ASD group, although the correlations between un/segmented Block Design and EFT performance for the TD group ($z_{r1r2}=1.58$, $p=.11$) and the group of matched controls ($z_{r1r2}=1.26$, $p=.21$) did not differ significantly from those demonstrated by the group of individuals with ASD. On the other hand, whereas the EFT (local processing) could be viewed as tapping the reverse process from the im/possible figures categorisation task (global processing) in the groups of TD children (ASD versus TD correlations; $z_{r1r2}=2.45$, $p=.01$) and matched controls (ASD versus matched control correlations; $z_{r1r2}=2.38$, $p=.02$), both of which are related to nonverbal ability level in these groups, the failure to find a significant correlation in the ASD group may again signal group-specific reliance on a completely separate process (or processes) when completing these two tasks.

Unique to the group of matched controls was a negative correlation between sentence completion error score and A' from the impossible figures categorisation task. This finding could reflect cross-domain central coherence, but more likely reflects shared reliance on IQ, particularly verbal ability, since controlling for vocabulary score (and age) resulted in the correlation falling below the designated significance level. Moreover, removal of outliers resulted in this association again failing to reach significance. The correlations of percentage of global matches provided on the Navon-type task with average time on the standard EFT were highly discrepant between individuals with ASD and the two control groups. Whereas they were significantly negatively correlated for the control groups, indicating that those who responded globally on the Navon-type task were faster on the standard EFT items, they were significantly positively related to one another within the group of children with ASD. Indeed these correlations were significantly different from one another in both cases (ASD versus matched controls, z_{r1r2}=2.27, p=.02; ASD versus TD children, z_{r1r2}=1.94, p=.05). This may provide further evidence that these two indices share nonverbal ability loadings for the control groups, whereas they are tapping IQ-independent central coherence in the ASD group. Also unique to the ASD group was a correlation indicating increased error score on the sentence completion task as percentage of global matches to Navon-type figures decreased. However, this finding should be evaluated cautiously, since the individuals with ASD clearly had a broader range of error scores on the sentence completion task than the comparison groups. Only within the group of TD children, after partialling out influences due to age and vocabulary score, percentage of RT savings from the presegmented condition of the Block Design task was negatively related to A' score on the im/possible figures categorisation task, indicating some shared underpinning, likely nonverbal IQ.

For all three groups, it was predicted that performance on the three time perception tasks would correlate with one another. Supporting this postulation, positive correlations were found between time estimation and time production performance for all three groups, indicating a shared core process across the groups. Shared by both the groups of TD children and matched controls were positive correlations between time production and time reproduction scores. Only amongst the TD children, time estimation performance correlated significantly with time reproduction performance. In contrast to these findings, time reproduction performance was isolated from performance on the other two time perception tasks in the ASD group. This group may have relied on different cognitive mechanisms when completing this task, though only one of the two differences in correlations between the TD and ASD children reached statistical significance (time reproduction and production: z_{r1r2}=2.13, p=.03; time reproduction and estimation: z_{r1r2}=1.60, p=.11).

Consistent with predictions that tasks with significant loading on g, such as IT, would correlate with one another, both TD children and matched control groups demonstrated positive correlations between average time on the standard EFT items and IT. Moreover, IT was related to IQ in only these two groups, not in the ASD group, although only one pair of these correlations was significantly discrepant (correlation of EFT and IT for ASD versus matched controls, $z_{obs}=2.38$, $p=.02$).

Within the sample of individuals with ASD, as IT increased (worsened), percentage of global matches on the Navon-type task decreased. However, unique to the ASD group was a significant positive correlation between vocabulary score and percentage of global matches provided on the Navon-type task. After factoring out vocabulary score (and age) from the correlation between IT and performance on the Navon-type task, this correlation fell below the significance threshold, indicating some possible shared reliance on verbal ability.

For individuals within the matched control group, as percentage of global matches on the Navon-type task increased so too did the proportional RT advantage in the predictable condition of the implicit learning task. However, the non-parametric correlation, which was most apt, did not reveal a significant correlation between these indices. As IT worsened amongst the matched controls, so too did the error score on the sentence completion task, which, like many other significant correlations reported here, likely reflects shared reliance on IQ, since this correlation was no longer significant after controlling for vocabulary score and age. Similarly, within the group of matched controls, as IT improved, A' also improved, yet this correlation fell below significance after controlling for age and vocabulary score. Possibly reflecting shared processing speed demands, only after controlling for age and vocabulary score did the time estimation difference score positively correlate with average time spent on standard EFT items amongst the matched controls.

Interestingly, only amongst the group of TD children, im/possible figures A' was significantly negatively correlated with all three time perception indices, with two correlations (with time production and reproduction) remaining significant even after controlling for age and IQ. Though A' was also significantly negatively correlated with time estimation performance amongst the ASD children, this correlation did not survive partialling out the influences of age and IQ.

Unique to the ASD group was a relationship indicating increased error score on the sentence completion task as discrepancy in time estimation increased. This may reflect significant hesitations, which are scored as a one in this task; though it is unclear why this finding would be unique to ASD and to the time estimation task (of the three time perception tasks). A likely explanation for the lack of a significant finding within the two comparison groups is the relatively (compared to that observed in the ASD group) restricted range of sentence completion error scores.

Unique to the group of TD children, time estimation discrepancy was positively correlated with IT and average time spent on standard EFT items. Time production was positively correlated with average time on standard EFT items but negatively correlated with percentage of RT savings on the presegmented condition of the Block Design task. Time production was also positively correlated with IT, but negatively correlated with A'. These findings may reflect a shared reliance on IQ (particularly verbal abilities) and age, since controlling for vocabulary score and age resulted in the first four correlations falling below the .05 significance level and caused the fifth and sixth to fall from the <.01 level to the .05 level.

In the TD group, several correlations dropped below the .05 significance level once outliers were removed, including time estimation performance with time reproduction and time production performance with IT. Outliers likely exerted disproportionate influence on these relationships.

Table 6–30. Correlation Matrix for All Experimental Tasks in the Group of TD Children Using Pearson's r (Spearman's rho).

		Time Prod Diff Sc (n=63)	Time Reprod Diff Sc (n=63)	IT (n=61)	RT Prop Stat Lrn (n=63)	Standard EFT Time (n=63)	Navon % Global (n=43)	Sent Comp Error (n=63)	Imp Fig A' (n=63)	Un/Seg BD % Savings (n=33)
Time Est Diff Sc (n=63)	Pearson	.75**	.47**‡	.31*	-.16	.26*	.11 (.07)	-.04 (-.14)	-.28*	-.28
	Age-Voc partial	.74**	.49**	.26	-.09	.17	.18	-.09	-.18	-.27
Time Prod Diff Sc	Pearson		.53**	.32*‡	-.09	.29*	.22 (.15)	.02 (-.04)	-.39**	-.37*
	Age-Voc partial		.58**	.28*	-.02	.16	.27	-.07	-.27*	-.34
Time Reprod Diff Sc	Pearson			.03	-.01	.05	.11 (.01)	-.01 (-.05)	-.29*	-.10
	Age-Voc partial			.02	.01	.09	.14	.02	-.38**	-.12
IT	Pearson				.08	.33*	.11 (-.03)	.06 (.10)	-.21	-.30
	Age-Voc partial				.14	.29*	.16	.03	-.13	-.29
RT Prop Stat Lrn	Pearson					-.14	.14 (.08)	-.06 (.08)	.07	.31
	Age-Voc partial					-.05	.10	-.02	-.05	.30
Standard EFT Time	Pearson						-.19 (-.34*)	.10 (.10)	-.54**	.35*
	Age-Voc partial						-.20	-.04	-.36**	.54**
Navon % Global	Pearson							.16 (.01)	-.06 (.21)	-.13 (-.27)
	Age-Voc partial							.16	-.11	-.12
Sent Comp Error	Pearson								-.24 (-.22)	.07 (.04)
	Age-Voc partial								-.12	.13
Imp Fig A'	Pearson									-.21
	Age-Voc partial									-.38*

*p<.05, **p<.01

‡ change in the significance level of a correlation with the removal of outliers

Table 6–31. Correlation Matrix for All Experimental Tasks in the ASD Group Using Pearson's r (Spearman's rho).

		Time Prod Diff Sc (n=25)	Time Reprod Diff Sc (n=25)	IT (n=23)	RT Prop Stat Lrn (n=28)	Standard EFT Time (n=28)	Navon % Global (n=27)	Sent Comp Error (n=28)	Imp Fig A' (n=26)	Un/Seg BD % Savings (n=25)
Time Est Diff Sc (n=25)	Pearson	.56**	.11	-.18	.02	-.16	-.38 (-.20)	.57** (.57**)	-.43*	.32
	Age-Voc partial	.43*	-.05	-.42	.01	-.24	-.27	.43*	-.21	.32
Time Prod Diff Sc	Pearson		.06	-.07	-.26	-.18	-.08 (-.13)	.27 (.32)	-.28	-.16
	Age-Voc partial		-.01	-.22	-.32	-.27	.03	.09	-.08	-.17
Time Reprod Diff Sc	Pearson			.39	.28	.01	-.07 (-.04)	.29 (.37)	-.01	-.08
	Age-Voc partial			.32	.28	.01	.08	.19	.22	-.27
IT	Pearson				.32	-.08	-.46* (-.41)	-.12 (.05)	.09	-.16
	Age-Voc partial				.32	-.10	-.39	.30	.31	-.28
RT Prop Stat Lrn	Pearson					.21	.03 (.07)	.09 (.18)	-.02	.04
	Age-Voc partial					.21	.05	.09	-.01	.03
Standard EFT Time	Pearson						.30 (.45*)	-.09 (-.18)	.01	.13
	Age-Voc partial						.34	-.14	.05	.16
Navon % Global	Pearson							-.41* (-.44*)	.17 (.11)	-.07 (-.20)
	Age-Voc partial							-.31	-.02	.04
Sent Comp Error	Pearson								-.24 (-.34)	.12 (.03)
	Age-Voc partial								.01	.04
Imp Fig A'	Pearson									-.25
	Age-Voc partial									-.17

$^{*}p<.05$, $^{**}p<.01$

Table 6–32. Correlation Matrix for All Experimental Tasks in the Group of Matched Controls Using Pearson's r (Spearman's rho).

		Time Prod Diff Sc (n=25)	Time Reprod Diff Sc (n=25)	IT (n=25)	RT Prop Stat Lrn (n=27)	Standard EFT Time (n=26)	Navon % Global (n=23)	Sent Comp Error (n=27)	Imp Fig A' (n=26)	Un/Seg BD % Savings (n=19)
Time Est Diff Sc (n=25)	Pearson	.80**	.13	-.09	-.10	.35	-.18 (-.40)	-.19 (-.25)	-.16	.05
	Age-Voc partial	.81**	.18	-.02	-.09	.41*	-.13	-.16	-.30	.10
Time Prod Diff Sc	Pearson		.43*	-.03	.14	.16	.03 (-.08)	-.14 (-.21)	-.04	-.16
	Age-Voc partial		.43*	.04	.12	.27	.04	-.07	-.18	-.15
Time Reprod Diff Sc	Pearson			.19	.31	.08	.14 (-.05)	.23 (-.01)	-.15	-.26
	Age-Voc partial			.22	.29	.24	.09	.38	-.33	-.33
IT	Pearson				.01	.60**	.10 (-.06)	.46* (.25)	-.58**	.27
	Age-Voc partial				.03	.60**	-.03	.16	-.38	.19
RT Prop Stat Lrn	Pearson					-.14	.51* (.40)	-.17 (-.01)	.26	.08
	Age-Voc partial					-.08	.52*	-.15	.27	.07
Standard EFT Time	Pearson						-.36 (-.50*)	.33 (.28)	-.61**	.44
	Age-Voc partial						-.44	.09	-.46*	.52*
Navon % Global	Pearson							.14 (-.19)	.08 (.46*)	.13 (-.09)
	Age-Voc partial							.04	.23	.07
Sent Comp Error	Pearson								-.64**‡ (-.45*)	.20 (.13)
	Age-Voc partial								-.35	.13
Imp Fig A'	Pearson									-.30
	Age-Voc partial									-.30

**p*<.05, ***p*<.01

‡ change in the significance level of a correlation with the removal of outliers

6.11 Subgroup Analyses within the ASD and TD Groups

In addition to the correlations performed above, the presence of potentially meaningful subgroups within the groups of ASD, TD, and MLD children was examined more thoroughly since they might reveal important relationships between experimental tasks. Performance on the most prototypical measures of central coherence, one verbal (i.e., the sentence completion task) and one nonverbal (i.e., the EFT) task, was used to split participant groups into subgroups since WCC is conceptualised in this thesis as a driving force behind savant skill development. Individuals were categorised as exhibiting robust WCC (n=18) if they both were as quick as the fastest third of the TD children on the standard EFT (28 seconds or less) and received an error score that was as high as the highest third amongst the TD children (2 or higher), while the other 77 individuals were classified as exhibiting strong central coherence. ANOVAs were used to compare the derived subgroups based on age, IQ, and experimental task performance. Group composition (particularly ASD and TD children since the number of MLD children [7] was very small) of these subgroups was examined via crosstabs analyses with non-parametric statistics (either Chi-square or Fisher's Exact Test, depending on the sample size of each subgroup). Consistent with the results presented earlier, children with ASD (n=13, 46%) were found to more likely exhibit WCC (p<.001) than were the TD children (n=4, 7%). Table 6-33 presents the age, IQ, and experimental task performance data for the WCC and strong CC subgroups. The WCC subgroup was both significantly older and lower functioning (as indexed by IQ scores) than the strong central coherence subgroup. Though experimental task performance was not significantly different between the groups, the WCC subgroup demonstrated consistently better mean scores on each of the three tasks than did the strong central coherence subgroup.

Table 6–33. Age, IQ Scores, and Experimental Task Performance for the WCC and Strong Central Coherence Subgroups.

	WCC (n=18)	Strong CC (n=77)	F	*p*	Cohen's *d*
Age	14.16 (2.34)	12.56 (2.45)	6.36	.01	0.67
Vocab	8.83 (3.84)	11.00 (3.41)	5.61	.02	0.60
Block Design	8.06 (4.05)	10.08 (3.53)	4.52	.04	0.53
FSIQ	91.28 (21.45)	103.23 (17.73)	6.12	.02	0.61
Implicit Learning	.13 (.14)	.10 (.14)	1.04	.31	0.21
Time Reprod	.97 (.09)	.94 (.11)	.89	.35	0.30
IT	44.35 (18.34)	39.92 (8.37)	.73	.40	0.31

An additional set of crosstab analyses were run in order to document possibly important subgroups based on performance across tasks measuring both central coherence and one or more of the other domains considered key to savant skill development. A similar metric (i.e., scoring as highly as the highest third of TD children) was used to create subgroups based on performance across the other key tasks (i.e., implicit learning [difference in proportion of savings between the first and second halves of the task ≥.14], time reproduction [average total difference score ≤.02], and IT [≤35]). Crosstabs with non-parametric statistics were run in order to determine if the TD or ASD groups were overrepresented amongst the derived subgroups. None of the other (non-WCC) cognitive domains produced differences in percentage of TD and ASD participants (*p*s>.10).

Nevertheless, the resulting subgroups were then collapsed with one another to form subgroups of individuals who both exhibited WCC and performed well in one other key cognitive domain. The percentage of TD and ASD children composing these smaller subgroups was then compared. Subgroups with significantly different compositions based on diagnosis were then subjected to ANOVAs to examine potential differences in age and IQ. Individuals who exhibited both WCC and good implicit learning were more likely (*p*=.03) to be members of the ASD group (n=5, 18%) than the TD group (n=2, 3%). Table 6-34 presents age and IQ data for the individuals comprising each of these subgroups; results indicated that individuals exhibiting both WCC and good implicit learning were older than those who exhibited strong central coherence and/or average implicit learning. The other two subgroups (WCC + good time reproduction and WCC + good IT) were represented fairly equally amongst the ASD and TD groups (*p*s>.10).

Table 6–34. Age and IQ Scores for Subgroups Based on WCC and Implicit Learning.

	WCC + Good Implicit Learning (n=7)	Strong CC and/or Average Implicit Learning (n=86)	F	*p*	Cohen's *d*
Age	14.56 (1.43)	12.69 (2.44)	4.00	.05	0.92
Vocab	9.71 (3.99)	10.66 (3.58)	0.45	.51	0.25
Block Design	8.57 (4.89)	9.78 (3.60)	0.69	.41	0.28
FSIQ	95.29 (24.25)	101.42 (18.58)	0.67	.41	0.28

6.12 Summary

The present chapter provided group-level analyses of performance on measures of WCC, implicit learning, time perception, and processing speed (see Table 6-35). Children with ASD were found to exhibit WCC on a number of measures when compared to performance by the matched controls. Implicit learning and processing speed were shown to be comparable between individuals with ASD and matched controls. Time perception was also found to be similar amongst matched controls and children with ASD, although there was a trend for individuals with ASD to be more accurate in time reproduction than matched controls. Gender differences in performance in these domains amongst the TD children were also examined, with some indication that females were better at implicit learning than males and that males were more detail focussed than were females. Individual differences were assessed through correlations (including age and IQ) and subgroup analyses. IT was found to correlate with IQ amongst the TD and MLD children, not the ASD children. Implicit learning performance was shown to be independent of age and IQ. Performance on several measures of local-global processing was shown to improve with age. Cross-task analyses indicated some unity of construct in time perception, and to a lesser extent in central coherence. Subgroup analyses indicated that individuals with WCC were much more likely to be from the ASD than from the TD group, and there was preliminary evidence to suggest that those who exhibited WCC and good implicit learning were more likely members of the ASD than the TD group. The implications of these findings are discussed in Chapter 7.

Table 6-35. Categorisation of ASD Performance on Experimental Tasks and Indication of Whether These Findings Replicated Previous Work.

Task	ASD Performance	Novel Finding or Replication
Implicit Learning	=	Novel
EFT	+	Replicates Shah & Frith, 1983; Jolliffe & Baron Cohen, 1997; Ropar & Mitchell, 2001
Un/Segmented Block Design	+	Replicates Shah & Frith, 1993
Categorisation of Im/Possible Figures	=	Novel
Navon Similarity Judgement	+	Replicates Rinehart et al., 2000; Behrmann et al., 2006
Sentence Completion	-	Replicates Happé et al., 2001
Time Estimation	=	Novel
Time Production	=	Novel
Time Reproduction	+	Novel
Inspection Time	=	Novel

+ superior

= intact

- impaired

Chapter 7: Discussion of Group Studies

As previously outlined in this thesis, various cognitive mechanisms in ASD were posited to contribute to the overrepresentation of savant skills in this population. These cognitive processes may be frankly different from what is seen in the context of typical development (e.g., WCC and perceptual skills) or may be intact and therefore serve a "gateway" function (e.g., implicit learning and information processing speed) to savant skill development. In other words, individuals without adequate ability in one or more (i.e., some combination of these) domains may not have the requisite cognitive skills for proceeding along the trajectory to savant skill development. The first step in addressing these hypotheses was to assess whether the proposed contributing cognitive processes were indeed different and/or intact when comparing performance on prototypical tasks between individuals with ASD and matched controls.

7.1 Weak Central Coherence

The first area of investigation was the purported cognitive style exhibited by individuals with ASD, in which local (vs. global) information is preferentially processed to an extent greater than that found amongst TD individuals. Individuals with ASD were predicted to exhibit WCC across modalities on a variety of prototypical tasks, resulting in a predictable pattern of strengths (good featural processing) and weaknesses (poor configural processing). For the most part, this prediction was upheld. First, these findings support the extant literature in demonstrating: 1) superiority for people with ASD in disembedding performance (Jolliffe & Baron-Cohen 1997; Ropar & Mitchell, 2001; Shah & Frith, 1983) and 2) facility in completing block construction tasks without presegmentation (Shah & Frith, 1993), but 3) difficulties in using context to process verbal information (Jolliffe & Baron-Cohen, 1999, 2000; Snowling & Frith, 1986). The present findings converge with a growing body of literature documenting this unusual cognitive style in ASD, particularly showing good performance when a task requires honing in on details and/or breaking down global forms into constituent parts. On the hybrid version of the EFT used here, individuals with ASD proved to be particularly able at finding hidden shapes. Moreover, the difference was most pronounced for the most difficult items, those intended for adults. Though the ASD superiority on the EFT is well-documented (Jolliffe & Baron-Cohen 1997; Ropar & Mitchell, 2001; Shah & Frith, 1983), the present results diverge from those by Brian and Bryson (1996) who used abstract, meaningless (i.e., not nameable with conventional labels) shapes to assess disembedding performance in ASD; they found no ASD superiority. In the current study, the items from the standard version of the EFT carried the difference between groups. The standard EFT items require the participant to find the hidden figure in a complex and abstract but meaningless line drawing, unlike the children's version of the task in which the smaller figure is embedded within a meaningful, nameable line drawing. The contradiction between the present results and the findings of Brian and Bryson is difficult to reconcile; nevertheless, it remains that the Brian and Bryson results are the outlier from an otherwise robust finding of good disembedding performance by individuals with ASD.

In an attempt to understand better the underlying processes leading to good performance on block construction tasks (e.g., Block Design) amongst individuals with ASD (Bartak, Rutter, & Cox, 1975; Happé, 1994b; Lincoln et al., 1995; Lockyer & Rutter, 1970; Rumsey, 1992), the present thesis corroborated a previous study by Shah and Frith (1993) in showing that individuals with ASD, unlike controls, benefited relatively little from pre-segmentation of the block designs to be copied. Even when accounting for baseline Block Design performance in order to ascertain a percentage gain in RT, individuals with ASD benefited less from presegmentation than did controls.

Previous research findings (Burnette et al., 2005; Happé, 1997; Jolliffe & Baron-Cohen, 1999; Lopez & Leekam, 2003) show that individuals with ASD have difficulty using context to inform appropriate verbal responses, such as the correct pronunciation of homographs. In line with predictions made in the present thesis, use of a sentence completion task (Happé & Booth, in preparation) demonstrated that individuals with ASD both show a greater tendency to complete sentence stems in a local fashion and take longer on average when presented with a sentence stem that "baited" the individual to complete it in a local manner. This indicated difficulty in utilising meaning from a beginning clause or phrase to inform its completion into a coherent sentence. Even when individuals with ASD supplied a globally coherent ending, they took longer to do so, which may reflect the need to inhibit their baseline, locally-oriented response. This finding serves to validate suspicions of poor global coherence in the verbal domain for children with ASD when moving beyond the single word level.

As reviewed in Chapter 2, results from studies incorporating Navon-type tasks have been mixed, with some showing lack of global precedence and/or local interference effects amongst individuals with ASD (e.g., Behrmann et al., 2006; Rinehart et al., 2000). However, other studies have documented patterns of performance similar to those of comparison groups, with global precedence and/or global interference effects (Mottron et al., 1999; Ozonoff et al., 1994). Results from the present thesis indicate that individuals with ASD, when asked to match stimuli at a local or global level, preferentially do so at the local level (across density levels); therefore, these results converge with those of Behrmann and colleagues (2006) and Rinehart and colleagues (2000). Nevertheless, several points should be kept in mind: 1) performance on Navon-type tasks is particularly susceptible to methodological alterations (Kimchi, 1992; Navon, 1977), 2) these tasks may not represent global and local "meaning" in the spirit of the original formulation of the WCC theory (Frith, 1989), and 3) demarcation of global and local processing in this forced choice format (i.e., it is either one or the other) may be misleading and affect results (Happé & Frith, 2006).

The hypotheses of good task performance on tasks assessing featural processing and local coherence were confirmed, but predictions of poor global coherence were only partially supported. Inconsistent with a global processing deficit in the visuospatial domain, individuals with autism, similar to matched controls, did not experience difficulty when asked to categorise figures as possible or impossible. However, individuals with ASD, unlike matched controls, did not exhibit a significant discrepancy in performance when comparing accuracy of identifying possible versus impossible figures. It may be that for matched controls and TD children the incongruity of the impossible figures resulted in a laborious serial search, while a sort of "pop-out effect" occurred when they were presented with possible figures. The im/possibility of the figures was manipulated on a global level in an attempt to avoid tapping into the autism facility for "spotting the difference" at a local level (e.g., O'Riordan & Plaisted, 2001). Nevertheless, this manipulation did not present a difficulty for individuals with autism. It may be that previous findings indicating difficulty for people with autism in identifying impossible figures (e.g., Rodgers, 2000) were not related to a global processing deficit. For example, anecdotal evidence from caregivers of individuals with autism suggests difficulties in depth perception, and this aspect of visual perception could be quite important to the discrimination of possible and impossible figures, which are often 2-D representations of 3-D figures.

Correlational analyses between measures of WCC and age and IQ, as well as between measures of WCC and other experimental tasks (including comparing performance between tasks measuring WCC) was examined to elucidate unique and shared cognitive processes across the participant groups. EFT performance was significantly positively correlated with Block Design score for the two comparison groups of TD children and matched controls, not for the group of individuals with ASD. Block Design, may, in the nonautistic groups, serve as a proxy for nonverbal IQ. Ability to quickly locate hidden figures was associated with better nonverbal ability scores in the two comparison groups, whereas good EFT performance may not be as reliant on good general nonverbal ability but indicative of a cognitive style independent of IQ in ASD. WISC Block Design confounds nonverbal IQ and central coherence; hence, reduced variance in performance is expected in individuals with ASD because all were predicted to exhibit WCC. Demonstrating shared cognitive demands, average time on the standard EFT items was negatively correlated with A' from the impossible figures categorisation task and positively correlated with RT gain on the un/segmented BD task for the groups of TD children and matched controls. In contrast, significant correlations between these task scores were not noted in the group of individuals with ASD, perhaps suggesting a unique approach by individuals with ASD and/or heavy reliance on general visuospatial abilities by the TD children and matched controls when completing the EFT. Unlike EFT, for the ASD and matched control groups, the total error score from the sentence completion task was found to correlate with its domain relevant IQ score, vocabulary score, in this case. Because of the wider range of ability levels in these two groups, this finding may indicate poorer use of context in less verbally able individuals and/or a more limited lexicon from which less verbally able individuals may derive "completions". Correlational analyses with the Navon-type task demonstrated that verbal ability is uniquely related to global response bias on this task, but only amongst individuals with ASD. Perhaps a verbal strategy employed by those with greater verbal ability contributed to processing this task at a global level. Providing indirect indication of different processing mechanisms underlying performance on the im/possible figures categorisation task, in the two comparison groups, Block Design score was significantly correlated with the ability to correctly identify impossible figures, but this relationship did not hold in the ASD group. As alluded to earlier, Block Design performance in ASD reflects both g and featural processing, the latter of which may have wiped out the potential for a positive correlation with impossible figure identification (due to general intelligence).

In an attempt to examine further individual differences potentially meaningful subgroups were identified based on shared good or poor performance across tasks tapping the four cognitive domains considered key to savant skill development. Within the ASD group, there was some indication of cross-domain central coherence from the subgroup analyses. Individuals who were fast on the EFT and provided local completions on the sentence completion task were much more likely to belong to the ASD than to the TD group, which corroborates means-level analyses discussed above.

Consistent with expectations and the majority of the extant literature (Baron-Cohen & Hammer, 1997; Voyer, Voyer, & Bryden, 1995), gender differences favouring TD males were noted for both total and average time per item on the entire hybrid EFT. This finding is consistent with predictions based on the "extreme male brain theory" of autism by Baron-Cohen (2002), which highlighted gender differences on this and other tasks as representative of the psychometrically defined "male brain". Better male performance was also found in the identification of impossible figures. Within the limited extant literature utilising this type of task, gender differences have not been reported. Nevertheless, given reports that males surpass females when completing some visuospatial tasks (e.g., Collins & Kimura, 1997; Linn & Peterson, 1985; Maccoby & Jacklin, 1974), it is not surprising to find better male performance when asked to identify impossible figures. However, this result could also be taken as evidence in support of better systemising (not WCC) for TD males versus TD females.

Underlying these gender differences in performance could be any number or combination of factors, such as prenatal hormonal effects as first proposed by Geschwind and Galaburda (1987) and later expanded and tested by Baron-Cohen and colleagues (Knickmeyer et al., 2005; Lutchmaya, Baron-Cohen, & Raggatt, 2002a, 2002b). This difference could also reflect other biological or "hard-wired" differences between genders, differences in experience/socialisation with visuospatial problem solving of this sort or, most likely, some combination of the two.

Developmental findings were also noted wherein the correct identification of possible and impossible figures increased with age for the group of TD children. Similarly, the percentage of correctly found embedded figures as well as the speed with which these figures were identified increased with age in this group. These findings are largely supported by the extant literature showing age-related increases in performance on both the im/possible figures identification task (Young & Deregowski, 1981) and the EFT (Witkin, Goodenough, & Karp, 1967). The research literature generally indicates that with age TD children tend to integrate more easily (both verbal and visual) information into coherent wholes (Kimchi, 1990) while also demonstrating increasing ability to ignore gestalt principles for detail-focussed processing (Pennings, 1988), both of which are consistent with the present findings.

Two overlapping limitations of the central coherence assessment battery utilised here are a general skew toward testing within the visuospatial domain and, more specifically, the lack of a verbal task to assess local superiority. The visuospatial tasks were well-balanced in terms of tasks that, if predictions held, would result in an ASD superiority (EFT, Block Design) versus an ASD deficit (Im/Possible figures, Navon-type task), while the one verbal task reported here predicted an ASD deficit. Future research should attempt to bridge this gap by developing a task designed to assess good featural processing within the verbal domain (e.g., spoonerisms and speech segmentation). This type of task would also assist in assessing the "centrality" or domain-general nature of central coherence, as originally conceptualised.

7.2 Implicit Learning

Amongst savants, anecdotal reports of remarkable memory and learning without conscious attempts to do so suggest that a second broad category of cognition, implicit learning, may provide a fruitful lead in attempting to better understand the root of savant skills. The highly structured nature of the savant talent domains informed the choice of a statistical learning task, in which a pattern of co-occurring shapes could be implicitly learned in contrast to shapes that occurred in a random order. Indeed, a learning effect, as demonstrated by a proportional RT saving between the predictable and unpredictable shape sequences, was shown by all groups; individuals with ASD, matched controls, and members of the group of TD children. However, the predicted ASD superiority in implicit learning was not supported. The learning effect, when accounting for baseline RT, was of a similar magnitude between children with ASD and matched controls. The present findings are consistent with one statistical learning study (Klinger et al., 2001) and two priming studies (Bowler et al., 1997; Renner et al., 2000) involving participants with ASD, but incongruous with findings from a serial reaction time study, which not only found ASD deficits in implicit learning, but also revealed no significant learning effect in this group (Mostofsky et al., 2000). A finding of intact implicit learning in this thesis does not necessarily resolve this debate, but it does indicate that individuals with ASD, unlike, for example, individuals with dyslexia (e.g., Stoodley, Harrison, & Stein, 2006) or Parkinson's disease (e.g., Jackson, Jackson, Harrison, Henderson, & Kennard, 1995), demonstrate intact serial reaction time learning.

Though the hypothesis of superior implicit learning in ASD was not supported, this cognitive mechanism could remain an important "gatekeeper" to savant-type and other skills. Perhaps children with ASD who possess intact implicit learning ability have the potential to develop savant-type skills, but only if adequate input (from a savant domain) is provided and if the individual is sufficiently motivated by the (savant domain) input to impute patterns. In this sense, assessing learning in a non-savant domain only serves as a proxy for savant-type learning and may even preclude the demonstration of superior learning. Nevertheless, the present findings indicate that visuospatial implicit learning is intact and therefore not contributing to the learning difficulties that individuals with ASD may experience.

Across all three groups, correlational analyses revealed no significant relationship between statistical learning and age or IQ, corroborating some (Meulemans et al., 1998; Vinter & Perruchet, 2000), but not all (e.g., Maybery et al., 1995; Thomas et al., 2004), studies in the extant implicit learning literature. Moreover, implicit learning performance for the ASD and matched control groups (with overall lower IQ scores) was comparable to that obtained by the TD group. Finally, implicit learning did not correlate significantly with scores on tasks assessing central coherence, time perception, or information processing efficiency administered in this thesis. Together, these findings indicate the independence of implicit learning systems from other cognitive processes in the context of typical development and ASD.

When examining potential gender differences in implicit learning, both TD males and TD females showed a learning effect, but proportional RT gain on each half of the task was significantly better in the female group. However, when comparing the difference in proportional RT gain between the first and second halves of the task, males and females demonstrated comparable improvement. Implicit learning effects are therefore comparable between genders. Greater female proportional RT gain may be due to males responding faster to the unpredictable sequence, thereby limiting the magnitude of their computed ratio.

Visuospatial implicit learning was intentionally chosen, since it was presumed to maximise performance amongst children with both ASD and intellectual impairment, given the traditional IQ profile in classic autism, favouring nonverbal skills. There could be undetermined group differences in implicit learning that are relegated to the verbal domain that may help to explain language difficulties. Moreover, assessing implicit learning in a domain novel to all participants would help to resolve issues of domain specific preference, though it may be equally intriguing to assess implicit learning within a savant domain amongst interested nonsavants.

7.3 Inspection Time

A third cognitive domain with potential relevance to savant skills is information processing speed. Failing to support the present hypothesis and corroborate previous findings, information processing efficiency, as measured by IT, was comparable between children with ASD and matched controls. Scheuffgen et al. (2000) demonstrated that children with ASD outperformed MLD children of similar age and IQ and scored comparably to age-matched TD children on the IT task. However, important differences arose when comparing characteristics of participants in the two studies. It could be that, in comparison to Scheuffgen and colleagues' study, the smaller number of children with MLD in both the ASD and matched control groups in the present study, masked potential group differences. Accordingly, possible ceiling effects and/or restricted range in performance may have contributed to failed replication, so that the IT of ASD children was more likely to be discrepant from expectations in the context of MLD than in the normal IQ control group. Perhaps poor processing efficiency (as shown by relatively slow IT) reflected a qualitative developmental difference between individuals with idiopathic intellectual impairment and individuals with both autism and intellectual impairment (Anderson, 2001). Learning difficulties due to autism do not compromise information processing speed whereas, based on the limited information currently available, other (sometimes unknown) causes of learning difficulties do.

Nevertheless, despite the failed replication of Scheuffgen et al.'s study, speed of information processing efficiency does not appear to serve the same functions in children with ASD as it does in TD children or children with MLD. Unique to the ASD group, IT did not correlate with the IQ measures whereas in the matched control group and group of TD children IT was significantly related to IQ measures, Block Design performance in particular. Similarly, EFT performance was not related to IT in the ASD group whereas they were significantly related to one another in the groups of matched controls and TD children. In these two comparison groups, EFT performance is related significantly to IQ, particularly Block Design score, which indicates that general cognitive ability is likely driving this relationship. Collectively, the correlational findings substantiate Scheuffgen et al.'s study and further support their argument that one or more non-processing speed factors contributed to lower (or in this thesis, variation in) traditionally measured IQ in ASD. Scheuffgen and colleagues proposed deficits in theory of mind as the key factor, since it may have particularly detrimental effects on opportunities for "social learning", used to convey knowledge. The present thesis did not speak directly to this secondary question, although the lack of any significant correlations between IT and the other non-social measures administered in this thesis did not contradict this postulation. As a contrast, for the matched control group, which included children with MLD and the group of TD children, numerous correlations between IT and tasks assessing central coherence, for example, reached significance. Moreover, correlations between time estimation and time production were significantly related to IT in the TD children's group.

Fractionation of processing speed from the typical cognitive architecture may assist in better understanding both assets and deficits in ASD. Indeed, speed of processing, like implicit learning, may also serve as a "gateway" function to savant skill development in ASD and prevent many individuals with idiopathic intellectual impairment from developing savant skills. The inclusion of savants with average range IQ may be a particularly effective strategy when attempting to better answer this question. Thus far, the case reports of savants involving the assessment of IT have revealed surprisingly good IT (Anderson et al., 1998; Young & Nettelbeck, 1995), but these savants also had intellectual impairments. Therefore, if savants with average range IQ have an IT commensurate with their IQ, then one could argue for a minimal processing speed requirement to develop savant skills. However, if IT superiorities are found amongst the normal IQ savants, then excellent IT, which would be more common for individuals with ASD and intellectual impairment than for individuals with idiopathic intellectual impairment, would be proposed to underlie savant skill development. The case studies described in Chapter 8, which include normal IQ savants, will address this question.

Typically, IT is conceptualised as measuring the potential for information processing; however, for individuals with ASD this potential is not cached out in the Wechsler Scales of Intelligence, since, outside of Block Design and perhaps a few other measures, the tasks measure socially acquired knowledge. The lack of cultural knowledge in ASD therefore serves as a limiting factor in measured IQ, while IT serves as a limiting factor for measured IQ in those with idiopathic intellectual impairment. In other words, the environment for those with ASD is different and therefore influencing IQ measured in this fashion, while processing speed is not limiting them. Indeed, the good processing efficiency that allows individuals with ASD to do well on IT tasks is not cached out in intelligence as measured by standard IQ tests. It may be that IT performance amongst individuals with ASD reflects the use of low-level perceptual discrimination that TD individuals do not use in completing this judgement.

7.4 Time Perception

The final cognitive domain of interest was perceptual functioning, particularly time perception, given reports of good appreciation for time in certain individuals with ASD (e.g., Treffert & Wallace, 2002). Three types of time perception tasks were utilised to assess relatively large time intervals: time estimation, time production, and time reproduction. Unlike the first two time perception tasks, no recoding is required for the time reproduction task; hence, an ASD superiority was predicted in the ability to reproduce a time passage. Time perception in individuals with ASD has been investigated previously in the context of one small study, which revealed deficits in their ability to reproduce accurately brief time intervals, on the order of two to three seconds (Szelag et al., 2004). Despite this documented deficit, methodological dissimilarities between that study and the present thesis, such as larger units of time to reproduce, resulted in predictions of ASD superiority. Individuals with ASD and matched controls demonstrated roughly equivalent performance on time estimation and production tasks, but, as predicted, there was some indication of better performance by the ASD group on the time reproduction task. Time reproduction requires the faithful reproduction of a time window, and thus retention of an unaltered memory trace is akin to many of the reports of good rote memory in ASD, whether savant (Mottron, Belleville, Stip, & Morasse, 1998; Spitz & LaFontaine, 1973) or nonsavant (Toichi & Kamio, 2002). If approached from this perspective, it is perhaps unsurprising to see good ASD performance on the time reproduction task in particular.

Unlike, for example, children and adults with ADHD (Barkley, Koplowitz, Anderson, & McMurray, 1997; Barkley et al., 2001; Kerns, McInerney, & Wilde, 2001; West et al., 2000), individuals with ASD performed comparably to sex, age, and IQ matched controls on these time perception tasks. Though the cognitive profiles of individuals with ASD and ADHD share in common attentional abnormalities, they are usually of a different nature and quality. It may be that inhibitory deficits (Barkley, 1997) and/or sub-optimal reward processes in the form of delay aversion (e.g., Kuntsi, Oosterlaan, & Stevenson, 2001; Sonuga-Barke, Williams, Hall, & Saxton, 1996), both of which characterise ADHD, are strong contributors to the difficulty children with

ADHD experience on time perception tasks. In contrast to these difficulties in ADHD, attentional abnormalities in ASD are described as a "narrowed attentional spotlight" or as over-focus, to the detriment of flexible shifting of the attentional spotlight, which has no significant negative bearing on time perception performance. Supporting this contention are arguments presented in the literature wherein time perception deficits in ADHD are underpinned by difficulties in behavioural inhibition (Barkley, 1997), a domain generally thought to be intact in ASD (e.g., Ozonoff & Strayer, 1997), or that children with delay aversion selectively attend to aspects of the environment that accelerate time passage (Sonuga-Barke, Saxton, & Hall, 1998).

Within task performance revealed various patterns of results. The time estimation ratio improved for both children with ASD and matched controls as the duration increased. In other words, they were proportionally more accurate as the duration to be estimated increased. In contrast, the ratio remained relatively similar across durations for both groups on the time production task. For time reproduction, the ratio in the ASD group trended toward decreasing as the duration increased, while the ratio remained relatively unchanged across durations for the matched control group. This improvement and stabilisation of ratios for the ASD group may reflect increased task difficulty at smaller time intervals. Regardless, this result lends further support to earlier reported findings of unique performance on the time reproduction task amongst individuals with ASD.

Examination of the relationship between IQ and time perception performance showed that vocabulary score was related to time estimation performance in opposite directions for the ASD (negative) versus the matched control and TD (positive) groups. The negative correlations in the ASD group may reflect strategy use, wherein, the more verbally able individuals were more likely to use a verbal strategy (e.g., "counting to oneself", such as "one Mississippi, two Mississippi", etc.) while the less verbally able individuals utilised a more perceptual strategy or a frank guess. When looking at cross experimental task correlations, positive correlations between time estimation discrepancy and sentence completion error score were limited to the ASD group. Only in the ASD group do these two variables also relate significantly with vocabulary score, which is likely driving this relationship.

Within the ASD group only, vocabulary scores were negatively related to time reproduction difference scores, which may indicate an advantageous use of verbally-mediated strategies unique to this group or at least differentiating members within this group. Again, more verbally able ASD individuals may use more verbal strategies than less able individuals.

Significant age relationships with performance on time perception tasks were found only in the TD group and were further limited to the time estimation task with outliers included and to the time production task. Whereas one could argue that time reproduction performance is partially mediated by rote memory since you are asked to faithfully reproduce a presented duration, time estimation and time production may rely on more frontally-mediated and later maturing brain circuits reflecting cognitive demands such as inhibitory control for time estimation and generativity for time production. These executive functions have been shown to mature and/or increase in capacity during childhood and adolescence (e.g., Luciana, Conklin, Hooper, & Yarger, 2005; Luna, Garver, Urban, Lazar, & Sweeney, 2004). Across all three groups time estimation scores and time production scores were positively related to one another, reflecting likely reliance on the same underlying processes. However, unique to the ASD group, time reproduction performance was not significantly related to performance on either the time estimation task or the time production task. This suggests separate cognitive processes contributing to time reproduction performance in the ASD group (perhaps a stronger reliance on rote memory) and may help to explain better performance by this group.

Across the three measures of time perception, males consistently outperformed females. The extant literature has produced mixed findings in support of gender differences in time perception; however, when differences have been found, they tend to indicate better precision in duration judgment for males (e.g., Block, Hancock, & Zakay, 2000; Rammsayer & Lustnauer, 1989; Roeckelein, 1972). The present study supports this trend in the literature. Indeed, the present results may reflect findings of gender differences in other cognitive domains such as episodic memory (e.g., Herlitz, Nilsson, & Bäckman, 1997) or arousal/speed of processing (e.g., Brocki & Bohlin, 2004) that may contribute to time perception performance. From functional neuroimaging studies and studies of patients with neurodegenerative disorders or lesions, it is clear that both time estimation and motor timing have been associated with the cerebellum as well as frontal regions and the basal ganglia (Rubia & Smith, 2004). Tying together these findings with gender differences in brain structure are results from Giedd (2004) showing that the cerebellum is the most gender dimorphic brain region during childhood and adolescence, even after controlling for differences in total cerebral volume. Perhaps gender differences in cerebellum underlie the time perception differences reported here and elsewhere, which could be the result of any number of factors, including gender-related experiential differences in timing related behaviours (e.g., sports).

A robust relationship has been demonstrated between attentional functioning and time perception in TD children (e.g., Zakay, 1992). Given the abnormal attention that characterises ASD, though not in inhibitory control (e.g., Ozonoff & Strayer, 1997), it may prove fruitful to examine the relationship between time perception and attentional functioning, in order to assess possible underlying mechanisms responsible for success and failure in ASD.

7.5 Subgroup Analyses

The choice of cognitive domains assessed in this thesis was not arbitrary, rather, each was considered a possible contributor to savant and splinter skill expression in ASD; therefore, the presence of potential subgroups based on shared good performance across tasks was examined across the participant groups, particularly the children with ASD and the TD children. Although power was limited, results from these crosstab analyses indicated that children with ASD were more likely to exhibit robust WCC (across the EFT and Sentence Completion task) than were the TD children, consistent with the means-based analyses. Examination of performance on all other key indices showed that children with ASD were as likely as TD children to exhibit good performance in terms of implicit learning, time perception, and processing speed. When searching for subgroups of individuals who scored highly on both WCC measures and one of the other key indices, it was found that those who exhibited both WCC and good implicit learning were more likely members of the ASD group than the TD group. This potentially informative subgroup may indicate a differently organised implicit learning system in ASD which may predispose these individuals to develop savant or savant-like skills in highly organised domains.

7.6 Summary

Overall, predictions of surprisingly good skills in featural processing and ability to faithfully reproduce a time passage were supported through significantly better performance by children with ASD as compared to controls. These unique elements of the cognitive profile in ASD may facilitate savant skill development in various domains. Moreover, the abilities postulated as intact and therefore required, but alone insufficient, for savant skill development (i.e., processing speed and implicit learning), were comparable between children with ASD and sex, age, and IQ matched controls. The next logical step to take in order to test predictions of relations between these key cognitive domains and savant skill development would involve assessment of individuals with savant skills. Chapter 8 presents a series of savant case studies in which these hypotheses are further tested by comparing performance on prototypical tasks between savants (two children and two adults) and small control groups matched for sex, age, and IQ.

Chapter 8: A Series of Four Savant Case Studies

8.1 Case Studies Introduction

This thesis aims to isolate those cognitive mechanisms that may contribute to savant skill development and explain the raised incidence of these skills in the context of ASD. As seen in the group study, performance on tasks from several cognitive domains was hypothesised to distinguish individuals with ASD from matched controls. For the most part, these hypotheses were validated. The first step was to identify through the group studies the characteristics that were plausibly related to savant skill development and whether they were more common in those with ASD than in matched controls. The second step was to examine whether these characteristics were particularly striking in those with ASD and savant skills versus those individuals without savant skills.

In order to assess these issues, data from four case studies are presented here. First, two relatively young savants with ASD were compared to two subgroups selected from the aforementioned group studies composed of: 1) age, gender, and IQ matched TD/MLD children and 2) a similarly matched group of general children with ASD. Second, two adult savants with ASD, but no learning difficulties, were assessed on a similar battery of tasks and had their performance compared to that of a small group of TD adults, recruited expressly for this purpose. In contrast to most of the extant literature, cognitively unimpaired savants were recruited for this series of case studies. From a theoretical standpoint, inclusion of intellectually unimpaired savants allows for interesting dissociations without having results tainted with cognitive disability. Moreover, the inclusion of savants with average range IQ allows for the examination of absolute superiorities in performance, not just superiorities relative to their own IQ as has been found for IT in previous savant case studies, for example (Anderson et al., 1998; Young & Nettelbeck, 1995).

Case studies are a common methodology employed by neuropsychologists in order to isolate the neural and/or cognitive in/dependence of various abilities. Particularly relevant are those individuals who exhibit exceptionally poor or good performance in select domains. Indeed, savants present a rare example of exceptionally good performance in isolated domains, often independent of intelligence or daily functioning. Single and double dissociations provide a powerful method for isolating contributory cognitive functions to various tasks. Dissociations may prove particularly informative in assessing the root of savant skills.

Based on findings from Chapters 2 through 4, WCC, good implicit learning, surprisingly fast IT, and good time perception (particularly time reproduction) were considered potentially important markers of cognitive mechanisms contributing to savant skill development. If these capacities facilitate savant skills, one might hypothesise superior performance in savants as compared to the comparison groups or if one hypothesises a gateway model, then one would expect equivalent savant and nonsavant ASD performance, but better performance in these groups than in a matched control group. The tasks presented in Chapters 5 and 6 were therefore used in the examination of the four cases, along with talent-specific assessment.

Table 8–1. Summary of Previous Case Studies of Savants, Organised by Domain of Talent

Authors	Participant(s)	Skill(s)	IQ	Controls	Main Findings
Calculation and Number Skills					
Horwitz et al., 1965	24-year-old male twins with MLD	Calendar Calc	FSIQ=60-70	None	In addition to calendar calculation, the twins can accurately answer if it was sunny, cloudy, or rainy, when given a date; George's calendar range is at least 6000 years; both twins could also answer accurately questions such as "in what years does 21 April fall on a Sunday?" or "what date is the 3rd Monday in April 1936?"; in contrast, neither twin can add, subtract, multiply, or divide simple, single digit numbers
Rubin & Monaghan, 1965	16-year-old female with visual impairment and MLD	Calendar Calc	WISC VIQ=51	5 same-age MLD girls with normal vision, 5 same-age TD girls with normal vision	Strong interest in calendars; calendar calculation accuracy far above that in the two control groups; ability to remember dates by association with particular incidents
Hoffman, 1971	13-year-old male with MLD and epilepsy	Calendar Calc	FSIQ=61	None	Difficulty with leap years limiting his range; based on report and deduction, he seems to have memorised a series of base dates from which he counts forward or backward to derive an answer
Hill, 1975	53-year-old male with MLD/encephalitis	Calendar Calc and Music	Stanford-Binet at age 6 years FSIQ=54	None	Did not demonstrate exceptional short-term memory (though digit span was higher than overall IQ), mental calculation, or eidetic memory; testing calendar performance did not reveal much in the way of systematic error or response patterns; he could mentally add single digit numbers, though he used his fingers for sums greater than 10

Authors	Participant(s)	Skill(s)	IQ	Controls	Main Findings
Burling et al., 1983	24-year-old male with MLD	Calendar Calc	WAIS FSIQ=53 VIQ=51 PIQ=60	None	Strong left hemisphere specialisation (as indicated by eye movements in response to questions presented bilaterally) for calendar questions while moderate for maths questions; no specialisation for music or spatial questions
Howe & Smith, 1988	14-year-old male with autism	Calendar Calc	WISC FSIQ=54	None	Calendar range of 1900-2060; interested in birthdays, memorising those of the staff members and other pupils; liked drawing calendars for particular months—on those drawings, some months were accompanied by what turned out to be (discovered through questioning) a representation of the moon; able to accurately answer questions such as "in what years will 9 October be on a Wednesday?"
Hurst & Mulhall, 1988	38-year-old male with autism	Calendar Calc	WAIS FSIQ=71 VIQ=68 PIQ=78	None	Calendar range of 1899-2011; difficulty with simple division; as an adolescent he would repeatedly read and memorise hospital telephone numbers from phone books
Dorman, 1991	18-year-old male with excised left hemisphere at 8 years	Calendar Calc	WAIS-R FSIQ=84 VIQ=81 PIQ=81	None	Reported visualising the current year's calendar before beginning serial calculations; better than chance though not exceptional by calendar savant standards; RT and accuracy were positively correlated with distance from the current year; concurrent verbal and visual working memory tasks did not significantly interfere with calendar performance

Authors	Participant(s)	Skill(s)	IQ	Controls	Main Findings
Ho et al., 1991	19-year-old male with MLD	Calendar Calc	WISC FSIQ=75 VIQ=66 PIQ=91	None	Only began calendar calculation three years prior to the study, but he had an unusual prior interest in reading and keeping calendars; no errors in 20th and 21st centuries; systematic errors were obtained for testing of dates before or after these centuries indicating consistent methodology; seemed to use the 28 year rule based on his occasional writings on paper during solution of problems; when given impossible dates, he gave answers at random and did not protest; for a 10 year span, was able to convert, without errors, the Gregorian calendar to the Chinese calendar; able to answer questions of the variety "what year is it when 15 March falls on a Friday?"; good visual digit span of 12 vs. auditory digit span of 7
Moriarty et al., 1993	17-year-old male with Tourette's syndrome	Calendar Calc	WAIS-R VIQ=74 PIQ=64	None	Unable to provide answers to calendar questions preceding his birth; could provide the day and date for past events he experienced; he could not explain how he answered these questions, but denied "remembering" them
Nelson & Pribor, 1993	44-year-old male with autism and Tourette's syndrome	Calendar Calc	VIQ<40 PIQ=66	None	Could open a box of matches, quickly close it and accurately estimate the number enclosed; yet he had impaired verbal and nonverbal memory at immediate and delayed recall
Pring & Hermelin, 2002	46-year-old male with autism	Calendar Calc	PPVT=78 Ravens=108	One TD adult, one mathematics Prof	Fast, spontaneous ability to recognise new simple rules and relationships; the savant's associative learning (of various letter-number combinations) was significantly better than that of the TD adult and comparable to that of the maths Prof

Authors	Participant(s)	Skill(s)	IQ	Controls	Main Findings
Boddaert et al., 2005	**22-year-old male with autism**	**Calendar Calc**	WAIS FSIQ=66 VIQ=83 PIQ=45	None	Using PET, calendar calculation was associated with a brain network (i.e., left hippocampus, left middle temporal gyrus, and left inferior frontal gyrus) previously implicated in studies of memory
Steel et al., 1984	**29-year-old male with autism**	**Math**	WAIS FSIQ=91 VIQ=94 PIQ=89	None	Excellent auditory rote memory (two tests of digit span) in contrast to poor executive functioning (Wisconsin Card Sorting Test, the Trail Making Test) and memory for complex visual (ROCF) and verbal (orally presented stories) material; scored 140 (at the 99th percentile) on a maths achievement test
Stevens & Moffitt, 1988	**34-year-old male with Asperger's syndrome**	Mental Calc	WAIS-R FSIQ=99 VIQ=114 PIQ=82	None	Ceiling performance on the Digit Span subtest of the WAIS-R reflecting excellent auditory rote memory (particularly for numbers), above average score on the Arithmetic subtest of the WAIS-R; knew simple rules (e.g., all squares end in the digits 0, 1, 4, 5, 6, 9) that aided his calculations
Kelly et al., 1997	**36-year-old male with autism**	Mental Calc	PPVT=52 Ravens=>90th %ile	5 high IQ TD adults	Faster and more accurate than controls in mentally solving multi-digit multiplication problems; with assistance, able to learn a novel algorithm based on converting Celsius to Fahrenheit, but practice brought only limited improvement
Anderson et al., 1998	**21-year-old male with autism**	Prime Number Calc	PPVT= unscorable Ravens=140	Expt 1: 1 adult male in his late 30s with a degree in maths and electronics; Expt 2: 7 2nd year undergrad males ages 19 to 20 majoring in maths	He was more accurate and quicker than the control in prime number identification; his IT was commensurate with an average to above average IQ, which contrasted with his verbal IQ; he utilises an established rule to calculate prime numbers

Authors	Participant(s)	Skill(s)	IQ	Controls	Main Findings
González-Garrido et al., 2002	16-year-old male with MLD	Mental Calc	WISC-R FSIQ=51 VIQ=47 PIQ=65	None	Impaired concept formation and colour-word interference effects; a structural brain scan (MRI) revealed increased volume in the right temporal region (reversed from normal); using SPECT during mental calc versus baseline, marked generalised increased perfusion, particularly over the right parietal region
Artistic Abilities					
Mottron & Belleville, 1993	34-36-year-old male with autism	Drawing	WAIS FSIQ=88	Control draughtsman	Unlike the control, he exhibited anomalous hierarchical organisation of local elements and global configuration of visual stimuli (Navon-type task, im/possible figure drawing, order of graphic recall)
Hermelin et al., 1999	46-year-old male with autism and visual impairment	Painting	PPVT=47 Ravens=55	None	Comparing photographs of models and resulting paintings demonstrates alterations due to his individual style and visual impairment as well as subtle memory transformations
Hou et al., 2000	9-year-old male with autism	Drawing	Scores not provided, but PIQ subtest performance in the average to below average range	None	Exceptional visual memory; SPECT shows bilaterally increased frontal perfusion and bilateral anterior temporal lobe hypoperfusion, which was more pronounced on the left than the right side; these findings parallel those of individuals with frontotemporal dementia who have developed art and other skills (or had the pre-existing skill altered) after onset of the dementia

Authors	Participant(s)	Skill(s)	IQ	Controls	Main Findings
Musical Ability					
Anastasi & Levee, 1960	35-year-old male with MLD	Music and Memory	WAIS FSIQ=73 VIQ=52 PIQ=92	None	Musical ability judged to be "outstanding"; after viewing a novel 2.5 page printed passage once or twice, he can reproduce verbatim its contents; he also displays an excellent memory for personal and historical events; scored at a superior level in recalling digits in a reversed order and in his memory for sentences
Hermelin et al., 1989	34-year-old male with MLD and cerebral palsy	Music	FSIQ=40	26-year-old male professional musician	In response to different styles of music for improvisation, he produced more music than the control; the improvisation of the control more closely reflected the melodic line, tonality, and texture of the piece while his improvisation included more cadenzas, transitions, and elaborations
Young & Nettelbeck, 1995	12-year-old male with autism	Music	WISC-R FSIQ=105 VIQ=100 PIQ=111	For IT: the savant's 15-year-old younger brother and his 11-year-old younger brother as well as the mean IT from a sample of 87 adults	His IT was commensurate with his older brother's but better than his younger brother's and those of adults on whom this IT task has been used; scored 140 on quantitative reasoning index of the Stanford-Binet; AP confirmed via two tests; he could accurately repeat, after hearing it only once, seven bars of a novel (to him) piece with only one (harmonic) note error; on the WISC, he obtained ceiling performance on the Block Design, Digit Span, and Coding/Digit Symbol subtests
Mottron et al., 1999	17-year-old female with autism	Music	WAIS-R FSIQ=71 VIQ=73 PIQ=70	CA and MA matched controls of various sample sizes (range=3-16) for neuropsych tasks as well as a sample of musicians (n=3) for musical tasks	Confirmed AP ability and exceptional long-term memory for musical pieces when played on a piano; intact hierarchical local-global processing; cognitively inflexible (WCST, Trails B, Alternate Uses Test)

Authors	Participant(s)	Skill(s)	IQ	Controls	Main Findings
Other Skills					
Brink, 1980	Adult male with a gunshot wound to the head, entering through the left temple at 9 years	Mechanical	None	None	Mechanical ability emerged after brain injury, in contrast to struggles in relearning language, reading, writing, and arithmetic
O'Connor et al., 1994	31-year-old male with autism	Foreign Languages	WAIS VIQ=98 PIQ=52	None	Good conceptual and functional lexical knowledge but limited syntax (based on native English) prevents native speaker-like fluency
Dowker et al., 1996	45-year-old female with Asperger's syndrome	Poetry	Inconclusive---because of non-cooperation and poor understanding of the requirements	Semi-professional female poet in her early 30s with physical and sensory disabilities including moderate hearing loss	Unlike the control, she shows poor formal language as opposed to good use of poetic devices (e.g., rhyme, alliteration, and metaphors), in-depth self-analysis, and detailed description of interpersonal relationships and of nature and landscapes
Mottron et al., 1996	36-year-old male with autism	Memory	WAIS-R estimated VIQ=65	8 IQ matched adults, 9 normal IQ adults, one overtrained adult	Recall of proper names (not common names or neologisms) superior to that for IQ matched controls and commensurate with that for individuals of higher IQ; similar frequency effects (better recall for more frequently occurring proper names) to controls; face recognition superior to IQ matched controls and commensurate with that of higher IQ controls; when asked to match proper names and professions with novel and famous faces, his performance was equivalent to that of matched controls

8.2 Review of Case Studies

Chapter 3 reviewed and discussed savant skills in general. In the present section, the focus is on case studies. Table 8-1 provides a summary of published empirically-based case studies and case histories on individuals with savant skills. From Table 8-1, a few trends were noted. For example, it can be seen that less than one-third of the studies included control groups and that the most studied skill was calendar calculation. Moreover, most of the studies involved adults and adolescents, rather than younger children, and though there have been reports of multiple skills possessed by a single individual (e.g., music and memory within this domain), there have been limited reports of skills cutting across more than one domain (e.g., music and maths). The new cases presented here complement and add to those shown above, since control groups were employed, only one of the four savants is a calendar calculator, two of the savants are children, and one of the savants presents skills in (at least) two domains: art and calendar calculation (as well as memory).

Furthermore, based on the wide array of studies shown in Table 8-1, it is clear that good memory skills and strong motivation/interest are common findings of in-depth studies of individuals with savant skills. There are indications that certain cognitive processes, while impaired (e.g., cognitive flexibility) or average (e.g., memory) on standardised neuropsychological assessment, may, in fact, be better when assessed within the savant domain. It should also be noted that many of the individuals listed in Table 8-1 have a label of MLD. This does not necessarily preclude an ASD, since many of these individuals did not have a diagnostic evaluation as part of their assessment. Indeed, in these case reports, many of the individuals labelled MLD were described as exhibiting features reminiscent of autism, such as preoccupation with certain topics or domains of interest as well as social difficulties.

Three savant domains, graphic art, calendar calculation, and mechanical skills are covered in the following case studies. Two of the savants are artists, one is both an artist and a calendar calculator, and one is a mechanical savant. The following sections review the small literatures on each of these domains and skills, with most information complementary to what was covered in Chapter 3.

8.2.1 Art

Savant artists are typically noted for their skills in reproduction and perspective, particularly in drawing and painting (Hermelin, 2001). One of the most striking and famous examples of exceptional artistic ability in the context of autism is Nadia, who was extensively studied by Selfe (1978, 1995). By three and half years of age, Nadia was drawing remarkably life-like horses in perspective. Interestingly, her drawing did not follow a typical developmental progression; instead, it was well refined from the outset and did not change much over time. Indeed, her work is a prototypical example of the "natural learning" phenomenon thought to represent the essence of a savant's early ability expression (see Chapter 3). Her drawings recreating horses with such rich detail and accuracy in terms of proportion and perspective were often based on pictures she had seen only once, reinforcing reports in the savant literature of the almost eidetic nature of the memory representation. However, as others have noted (e.g., Pring & Hermelin, 1993), the reproductions were not simple copies; rather, the output by Nadia and others showed their own "highly personalised style".

Striving to better understand the mechanisms that underlie such striking artistic skill led several researchers to conduct case studies and, where possible, group studies on artistic savants, such as the seminal work by O'Connor and Hermelin. In a series of cleverly designed experiments, these investigators (Hermelin & O'Connor, 1990b; O'Connor & Hermelin, 1987a, 1987b, 1990) showed that savant artists' visuospatial recall and recognition were commensurate with their IQ, but their picture matching and graphic copying skills were commensurate with those of TD talented controls.

Further research went beyond examining general memory and drawing skills in savant artists to include the assessment of more specific cognitive mechanisms, such as perceptual abilities and information-processing style. One study indicates that, compared to a control group matched for nonverbal IQ and diagnosis, savant artists with autism have superior perceptual-motor skills; they were less likely to commit errors in mirror drawings and on tests of fine motor skill while they were both quicker and more accurate in completing jigsaw puzzles (Hermelin, Pring, & Heavey, 1994). Mottron and Belleville (1993) completed a case study of an artist with high-functioning autism. Reminiscent of WCC as discussed in Chapter 2, the artist's method of approaching the sketch was to proceed from one detail (or segment of the total picture) to the next in a serial fashion, rather than start with the whole sketch and work down to the details. Moreover, Pring and colleagues (1995) showed that preference for detail-focussed information processing may be a shared skill between savant artists with autism and artists without a developmental disability. In other words, the ability to see the gestalt or whole in terms of its constituent parts may facilitate the emergence of artistic talents in all individuals, not simply those with ASD. Corroborating this notion is the anecdotal evidence that classes for teaching drawing skills to children and adults often ask students to copy upside-down pictures. Presumably, part of the reason for this approach is to have people adopt a more part-oriented style, disrupting their usual configural bias.

As mentioned in Chapter 3, there are also reports of savant-type skills in art within non-ASD populations. For example, Miller and colleagues (Miller et al., 1996) described five previously non-disabled patients with frontotemporal dementia (FTD) who acquired new artistic skills with the onset of FTD. Several of these individuals had no previous history of particular artistic abilities, yet prodigious art skills emerged as the dementia progressed. Consistent with characteristics and traits of many savants, the modality of skill expression in these five, older adults was visual, not verbal; the images were meticulous copies that lacked abstract or symbolic qualities; episodic memory was preserved but semantic memory was devastated; and there was intense, obsessive preoccupation with the artwork. The authors hypothesised that selective degeneration of the anterior temporal and orbitofrontal cortices decreased inhibition of visual systems involved with perception, thereby enhancing artistic interest and abilities. Kapur (1996) refers to such processes as "paradoxical functional facilitation" and speculated that this process accounts for unexpected behavioural improvement in discrete domains following brain injury. Snyder and Mitchell (1999) argue that savant brain processes occur in each of us but are overwhelmed by more sophisticated conceptual cognition, which is also reminiscent of the seminal description of WCC by Frith (1989) indicating that individuals with autism focus on the "trees" rather than the "forest". Snyder and Mitchell conclude that savants with autism "have privileged access to lower levels of information not normally available through introspection". Snyder and colleagues (2003) tested this hypothesis in 11 male volunteers using transcranial magnetic stimulation (TMS) applied to approximately the left frontotemporal cortex while they carried out two drawing tests. TMS did not lead to any systematic improvement in naturalistic drawing ability, but it did lead to stylistic change in the drawings of four of the 11 participants. In a similar study using TMS to attempt to induce savant-level skills in 17 normal volunteers, Morrell and colleagues (2000), using a wide variety of tasks specifically designed to test savant abilities, failed to find skill enhancement. They concluded that the potential for savant skills may be limited to a small proportion of TD people just as they appear to be in people with developmental disabilities. These TMS studies therefore highlight the specialised nature of cognitive processes underlying savant performance in a select subset of individuals despite claims that these skills lie dormant in us all. Moreover, TMS is a powerful technique for localising potentially important neuroanatomical regions, but equally suffers from a one point in time perspective. In other words, utilising TMS to interfere with a potentially important brain region (e.g., frontotemporal cortex) in adults ignores important developmental aspects of skill development; interfering with this region is not the same as growing up with this skill.

In line with the extant literature, the three savant artist case studies reported here draw on the findings presented above through examination of general cognitive mechanisms like visuospatial recognition memory and general spatial abilities, while also extending this line of inquiry by investigating other mechanisms, such as central coherence, visuospatial implicit learning, and information processing efficiency.

8.2.2 Calendar Calculation

Perhaps the most idiosyncratic and therefore mysterious skill, commonly exhibited by savants, is calendar calculation. Calendar calculation is the skill of naming the day of the week on which a particular date (past, present, or future) has fallen or will fall. Calendar calculation is among the most prevalent of savant skills reported in autism (Rimland, 1978; Treffert, 1988), is quite amenable to testing, and represents the only skill in which savants surpass the performance of nondisabled "professional performers" (Ericsson & Faivre, 1988). Although it remains unclear as to why savants are drawn to calendars, how they complete calendar calculation is better understood. Memorisation would be the simplest explanation to account for this ability and may indeed best describe the mechanism responsible for those calendrical savants with a range limited to dates they have either experienced or seen on a calendar (Young & Nettelbeck, 1994). However, the savants with a greater range and those who show systematic errors in their calendar calculation provide evidence against memory as the sole underlying mechanism driving this skill (Cowan et al., 2003). Indeed, it has been shown that calendar savants have knowledge of calendar regularities and utilise them in their calculations (Cowan et al., 2001; Cowan et al., 2004; Hermelin & O'Connor, 1986; Ho et al., 1991; O'Connor & Hermelin, 1984). For example, in their seminal work, Hermelin and O'Connor (1986) documented the (implicit) use of two rules in a group of eight calendrical savants, the corresponding months rule and the 28-year rule. Importantly, this rule-use by savants showed that savant skills are not merely feats of rote memory.

Similarly, good basic, particularly mental, arithmetic skills, though not required for calendar calculation, have been shown to influence calendar range (Cowan et al., 2003; Rumsey et al., 1992). Nevertheless, given that arithmetic skills may be related to calendar calculation ability, consideration should be given to studies examining cases of good mental calculation. Investigators have begun to examine the brain basis of these mental calculating skills. Utilising PET, Pesenti and colleagues (2001) compared brain activation patterns between TD controls and an arithmetic prodigy (RG) as they performed mental calculations. When completing simple calculations, both the expert and non-experts showed activation in the brain bilaterally. However, when RG accurately and quickly completed more complex calculations, in contrast to controls, he recruited a system of brain areas implicated in episodic memory, including right medial frontal and parahippocampal regions. This finding corresponded to a previous behavioural case study involving RG (Pesenti, Seron, Samson, & Duroux, 1999), which showed that RG not only had a greater short-term memory store for numerical information than did controls, but that he also had a great deal of arithmetic data readily and quickly available via long-term memory. In this way, he exploited the unlimited storage capacity of long-term memory to maintain the sequence of steps and intermediate results needed for the more complex calculations. The non-expert group relied on more typical and limited span short-term working memory. Pesenti et al.'s study (2001) stands out not only because it designates unique brain mechanisms in the expert when he performs his special skill, but also suggests that the prodigy is relying on some special memory recruitment when performing his skill, as may be the case for certain other savants.

These findings underscore the need to examine not only calendar calculation strategies, but also domain general mechanisms that may contribute to skill development and magnitude, such as memory and speed of information processing, in the case presented later in this chapter.

8.2.3 Mechanical Aptitude

Very few cases of savants with mechanical skill have been described in the extant literature, though there have been a number of anecdotal and research (e.g., Baron-Cohen & Wheelwright, 1999) reports of children with autism who are fascinated by various machines. Nevertheless, several striking reports have been given, including the famous "Genius of Earlswood Asylum" (Sano, 1918; Tredgold, 1914), who, in spite of his struggles to communicate using functional language, became a skilled carpenter and cabinet maker while at Earlswood. He was provided the freedom and means to pursue his craft in full, including his own workshop; even achieving celebrity while at Earlswood, where his skill was acclaimed by both the Queen and Prince Consort at the time. Another case involved a nine-year-old boy who suffered a gunshot wound to the left side of his head, and some years later developed remarkable mechanical skill (Brink, 1980), while continuing to struggle in his efforts to relearn lost linguistic and arithmetic skills. Importantly, Brink points out that a high level of motivation and intense practice were key elements to his skill. An example of his skill was provided: "without instruction, he dismantled, reassembled, and modified several multi-gear bicycles." Another case was briefly discussed by Hoffman and Reeves (1979), in which an adult with MLD (nonverbal IQ in the range of 55-65) and a keen, long-time interest in working with machinery, could repair a broken alarm clock and a bike with several defects. Perhaps most pertinently, mechanical skills have been alluded to in some detail recently by Baron-Cohen and his colleagues (e.g., Baron-Cohen, Knickmeyer, & Belmonte, 2005) when discussing systemising, as previously reviewed in Chapter 2. Most of this work has relied on questionnaires to assess interests and behaviours thought to reflect a bias toward and/or facility with systemising. However, Baron-Cohen et al. (2001) devised a task to assess intuitive or folk physics (one's understanding of the physical causal world), with only real world experience to guide these deductions. In other words, this task is appropriate for those who have no knowledge of physics *per se*. Baron-Cohen and colleagues administered this task to a group of individuals with ASD and to controls and, as predicted, individuals with ASD outperformed the control participants.

Therefore, it may be a combination of the intuitive understanding of physical properties of the world along with an intense interest in machines of varying sorts that lead to the anecdotally reported mechanical aptitude in some individuals with ASD. A case study of a mechanical savant is reported here in order to examine these and other possibly relevant factors that may contribute to the development of his mechanical skills.

8.3 New Savant Case Studies

8.3.1 Hypotheses

In comparison to age and IQ matched TD and MLD participants, it was predicted that all savants would exhibit:

1) a weaker drive for central coherence,
2) superior implicit learning,
3) superior IT, and
4) superior time reproduction abilities.

In comparison to existing norms, it was predicted that all savants would exhibit: 1) superior recognition memory and 2) superior spatial reasoning abilities.

In comparison to age and IQ matched ASD participants, it was predicted that the (two child) savants would show superior implicit learning.

8.3.2 Comparison Groups

From the earlier described group studies, two control groups were chosen for the two young savants (VT and NC), one matched on gender, age, and IQ and another matched on the same dimensions, but with the additional match on diagnosis (i.e., ASD).

A group of TD or MLD (six for case VT and 12 for case NC) boys and six ASD boys were group matched to each of the child savants based on their age and IQ. Because VT scored in the borderline range on his IQ, his control group was limited in size (as compared to the control group for NC). Only boys were chosen since VT and NC are male and since gender differences in performance were noted on some of the tests administered to all participants.

Seven adult males of approximately the same age and IQ levels were recruited to serve as controls for both adult cases, MG and NH. Since both MG and NH scored in the average or higher range on the IQ test and due to concerns regarding developmental differences in performance on the experimental tasks, only TD adults were used as a comparison group. Again, only males were chosen, since both MG and NH are male and since gender differences are commonly noted on some of the tests within the following battery.

8.3.3 Test Battery

Many of the tests utilised here were those previously described in the methods section for the group studies including: EFT, Sentence Completion, Categorisation of Im/Possible Figures, IT, Implicit Learning, Navon Similarity Judgement task, and Time Perception. Whenever possible, all of these tasks were administered; however, time constraints, computer malfunction, or refusal by the participant resulted in administration of a few of these tasks to a subset of the four savants. Other tasks, some of which were standardised with well-established norms, were administered to each of the savants (when possible), in order to assess his performance against the wider population of same age peers. These tasks included two subtests from the Woodcock Johnson Cognitive Battery-Revised (WJ-R) selected to provide a metric of visuospatial recognition memory and spatial abilities, both of which may have relevance to artistic and mechanical abilities.

Picture Recognition-This subtest from the WJ-R is a visuospatial recognition task in which the participant was asked to view simultaneously for approximately five seconds a number of line drawings of everyday objects. Then, the page was flipped and either all or most of the line drawings were presented again, along with a number of distracter line drawings. The participant was asked to point out only those objects he had seen earlier. The response was considered correct only if he accurately recognised all of the objects. Varieties of the same object class (e.g., differently styled windows) were utilised in order to minimise the influence of verbal mediation as a strategy for remembering the objects. Item difficulty, manipulated by increasing the number of target and distracter stimuli, increased as the participant proceeded.

Spatial Relations-In this subtest, the participant is presented a series of shapes or parts from which he must select all those parts that form a target whole or complete shape. As with the aforementioned subtest, as the participant progresses through the task, the items get more difficult; this time because the shapes become increasingly abstract and complex.

8.3.4 Questionnaires

Questionnaires provided assessment of everyday behaviour and tendencies. One questionnaire, the Social Communication Questionnaire, was chosen to be completed by caregivers of the savants as a confirmation of their ASD diagnosis. Additional self-rating questionnaires were administered to the two adult savants and members of the TD adult control group in order to assess and compare individual differences in traits reminiscent of ASD and in sensory-perceptual processing.

Social Communication Questionnaire (SCQ; Berument et al., 1999)-Adapted from the Autism Diagnostic Interview, the lifetime version of the SCQ, designed for the detection of ASD in individuals ages 4-40 years, is appropriate for completion by a knowledgeable caregiver. Berument and colleagues reported that a cut-off score of 15 was most effective in discriminating individuals with ASD from those without ASD.

This screening tool was administered to caregivers of three of the four savants. NH did not have the SCQ completed because of his reticence toward having his parents participate in the study.

The two adult cases, MG and NH, and their matched controls, were also asked to fill out questionnaires about their own behaviour. Three of the questionnaires chosen, the Autism spectrum Quotient (AQ) (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) as well as the Empathising Quotient (EQ) and Systemising Quotient (SQ) (Baron-Cohen et al., 2003), were utilised to assess autistic traits and their tendency to "empathise" and to "systemise" in everyday contexts. All three questionnaires are self-ratings and have been validated in terms of distinguishing high functioning people on the autism spectrum from TD adults. The two adult cases and the TD adult control group also provided self-reports of their sensory preferences and dislikes by completing the Adult Sensory Profile (Brown & Dunn, 2002), which provides an index of sensory sensitivity, tendency to avoid sensations, low registration of sensory information, and tendency to seek out sensations. All of these indices were assessed across multiple modalities, including olfactory, motor, visual, tactile, and auditory systems. In addition to quantitative scores for each of these indices, this instrument also provides a qualitative five point categorical rating (ranging from 'very low' to 'low' to 'average' to 'high' to 'very high') on the continuum of possible scores.

The two adult savants and their matched controls as well as the young mechanical savant were also asked to complete the Folk Physics Test (Baron-Cohen et al., 2001). The Folk Physics Test is composed of 20 multiple-choice questions designed to assess one's understanding of the workings of macro- (e.g., gravity) and micro-level physical systems. According to Baron-Cohen and colleagues (2001), these problems can be solved from everyday experience with the physical world. As a complement to the SQ, the Folk Physics Test also provides a good measure of systemising abilities.

Whenever possible, an evaluation of savant skill level was made (partly based on expert judges, when appropriate). In line with Young's (1995) findings, savant status in this thesis was reserved for individuals whose skill level would be considered remarkable compared to other individuals with disabilities (talented), if not compared to anyone (prodigious). To this end, at the beginning of the discussion of results for each of the savant cases, a conservative savant level categorisation is made.

And finally, it should be noted that one of the savants (MG) had received, relatively recently, a clinical neuropsychological evaluation. Since some of the tasks utilised during testing were relevant to the questions posed here, these results are reported along with a brief description of the tasks in the context of his case study.

8.3.5 Data Analytic Approach

Case studies present their own brand of challenges in terms of data analysis. However, recent advances in statistical approaches to comparing scores from a single case to mean scores from a control group, even with a small sample size, have allowed for quantitative approaches to case studies. Work by Crawford and colleagues (e.g., Crawford & Howell, 1998) served as the basis for the data analytic approach to the following case studies. They advocate the use of a modified t-test in order to test whether the case's scores are significantly different from those of a small control group. Since their initial paper, Crawford and colleagues have published a number of papers validating the use of the modified t-test and other procedures for comparing performance between a single case and controls (Crawford, Howell, & Garthwaite, 1998; Crawford & Garthwaite, 2004). Indeed, one recent simulation (Crawford & Garthwaite, 2005) has confirmed the robustness of the modified t-test against Type I error rate, even when the sample size of the control group was five individuals.

8.4 Case 1: VT

8.4.1 Description

VT presented as a delightful 11-year-old who seemed to enjoy talking about his artwork and his desire to one day visit New York City.

VT currently carries the diagnosis of Asperger's syndrome. Indeed, VT's early development was remarkable, as described by his mother. "He didn't smile much and when he started talking, it was mostly to himself, not to us. His favourite game was simply lining up cars, not playing with them." VT's mother mentioned a time of increasing worry, after VT's younger sister was born. VT didn't show any interest in her at all. "He was neither jealous nor affectionate; he simply ignored her." After joining nursery school, his behaviour had become both idiosyncratic and disruptive. "He didn't play with toys or join in activities." Unfortunately, at that time, he could not handle simultaneously a pen and paper, which further limited possible avenues of expression. The result was VT becoming the loner of the class and if something upset him he would have a tantrum. Nevertheless, after some time, VT began to develop adequate fine motor skills sufficient to hold a pen and paper. Indeed, his mother noted that "from very early on VT began to show a vivid interest in drawing."

Subsequently, VT attended a weekly art class during which his teacher let him "do his own thing" while the rest of the class worked on a preset assignment. The teacher then suggested that VT present his work at the end of year show. At age nine, VT was the only child to exhibit a drawing.

VT's family history is also noteworthy. VT's mother reports that her sister's son has been diagnosed with Asperger's syndrome and that one of his uncles has cerebral palsy.

8.4.2 Special Skills

Beate Hermelin, one of the foremost world experts on savants, said about VT: "he clearly is a savant...VT's gift shows two characteristics which are rare amongst savant artists: (the artistic skill was) shown at an early age and he works primarily from his imagination rather than from models."

The images VT produces are full of both precision and expressiveness according to many objective viewers. Indeed, some of his drawings are so detailed, at such a minute level, that a magnifying glass may be required in order to see the facial expressions of the characters.

Much of his subject matter involves the "Beanies", a group of characters that "perform magic, change words round the wrong way, go on adventures to a different dimension, and have sharks follow them everywhere"; this last feature due to a visit (by VT and his family) to the sea life centre.

A number of cartoonists have observed and commented on VT's work. For example, Hurt Emerson, a professional cartoonist and illustrator, said the following about VT: "(he) has the promise to be a most original, graphic artist. He shows an exceptional talent, a very lively sense of humour, and a fluid, constantly surprising imagination." Clive Collins, another professional cartoonist, said about VT: "whenever children draw, they tend to avoid detail, but VT's (drawings) are full of detail. The New York skyscraper scene is amazing." And finally, Steve Chadburn, a cartoonist, said that "(VT) would put most of my students to shame. The line work shows a confident, purposeful hand. His understanding of perspective goes far beyond his age and the use of tonal values which break the pictures up is simply excellent."

In describing his approach to drawing VT had the following to say; "I don't usually have a particular plan for a picture. I just put down on paper what's in my imagination."

See Figure 8-1 and Appendix C for examples of VT's artwork.

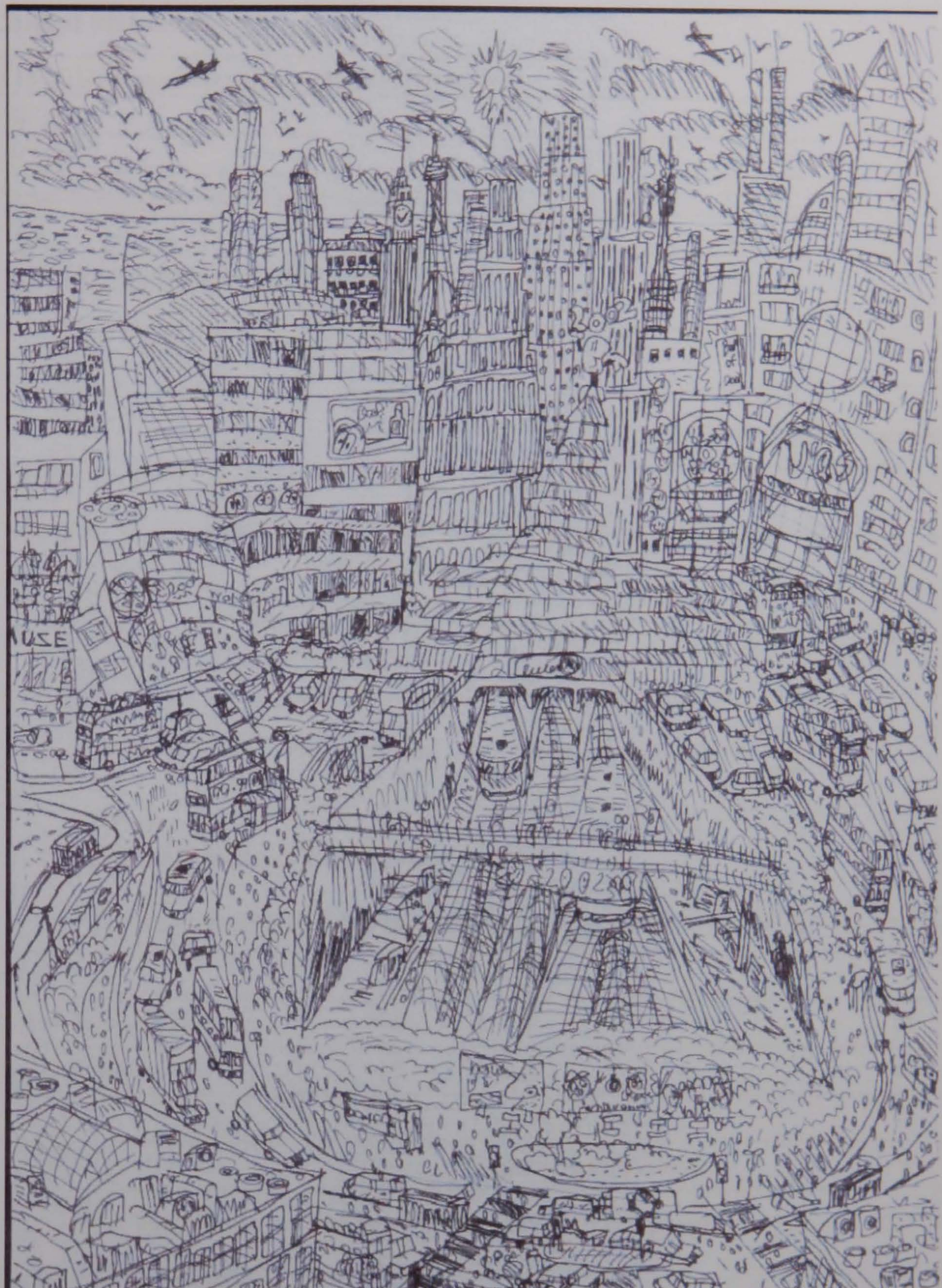


Figure 8–1. Example of VT's Artwork.

8.4.3 Results and Interpretation

Clinical Measures:

WISC-III (Administered in 1999; see Figure 8-2)	
FSIQ:	78
VIQ:	75
Verbal Comprehension: (Info+Sim+Voc+Com)	77
PIQ:	86
Perceptual Organisation: (PC+PA+BD+OA)	100

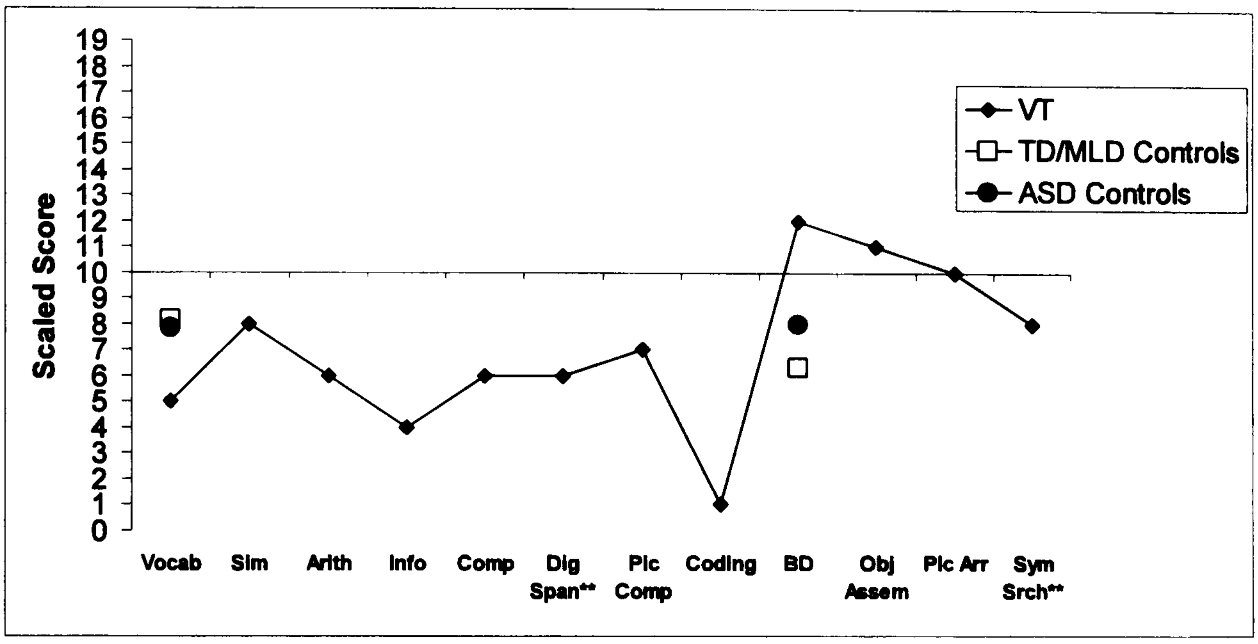


Figure 8–2. Profile of VT's IQ Scores.

** - supplementary subtests not utilised in the calculation of FSIQ, VIQ, or PIQ

WJ-R		SCQ✱	
Picture Recognition	146	Total	21
Spatial Relations	115	Social	10
		Communication	7
		Repetitive Behaviours	4

✱ A Total Score ≥ 15 is consistent with an ASD diagnosis

Experimental Measures

Table 8-2 presents IQ and experimental task results for VT as well as those of his two comparison groups. VT's IQ, EFT, and sentence completion data were obtained in the context of another study conducted by Dr. Happé and colleagues. The age at which these tests were administered is noted below.

Table 8–2. Performance on Tasks Administered to VT and Matched Controls: Mean (SD).

Test	VT	TD/MLD Control Group (n=6)	t	*p*	ASD Control Group (n=6)	t	*p*
Age	11.58	10.71 (1.44)	0.56	.60	12.56 (1.60)	0.57	.60
FSIQ†	78	84.33 (11.57)	0.51	.63	82.5 (10.43)	0.40	.71
Vocabulary	5	8.17 (3.19)	0.92	.40	7.83 (2.14)	1.22	.28
Block Design	12	6.33 (2.80)	1.87	.12	8.00 (2.45)	1.51	.19
EFT†							
% Corr All	87	52 (8)	4.05	.01	82 (12)	0.39	.72
Avg Time All	14.67	34.99 (5.55)	3.39	.02	24.26 (5.37)	1.65	.16
% Corr Adult Items	88	7 (11)	6.82	.001	75 (22)	0.55	.61
Avg Time Adult Items	13.88	57.67 (3.64)	11.14	.0001	28.81 (10.69)	1.29	.25
Navon							
% Glob Match	66.7	89.33 (4.78)	4.38	.007	65.75 (39.49)	0.02	.98
Implicit Learning							
Prop RT Gain between 1st & 2nd Halves	.21	.18 (.15)	0.19	.86	.20 (.19)	0.05	.96
Prop RT on 2nd Half	.31	.11 (.08)	2.31	.07	.17 (.09)	1.44	.21
Sentence Comp†							
No. of Loc Comp	2	0.83 (0.75)	1.44	.21	1.83 (1.33)	0.12	.91
Im/Poss Fig Cat							
No. Corr Poss Fig	8	6.17 (1.17)	1.45	.21	6.33 (2.07)	0.75	.49
Avg RT to Corr Poss Fig	1716	1568.50 (603.40)	0.23	.83	1589.17 (281.23)	0.42	.69
No. Corr Imp Fig	7	5.33 (1.37)	1.13	.31	6.00 (2.61)	0.35	.74
Avg RT to Corr Imp Fig	2277	1896.50 (748.23)	0.47	.66	1652.33 (313.70)	1.84	.12
Time Perception							
Time Est Ratio	.81	1.13 (0.20)	1.48	.20	1.32 (0.36)	1.31	.25
Time Prod Ratio	.77	0.73 (0.24)	0.15	.88	0.75 (0.26)	0.07	.95
Time Rep Ratio	.82	0.90 (0.14)	0.53	.62	0.99 (0.10)	1.57	.18
Time Est Discrep	.19	0.14 (0.19)	0.24	.82	0.41 (0.23)	0.89	.42
Time Prod Discrep	.23	0.27 (0.24)	0.15	.88	0.29 (0.20)	0.28	.79
Time Rep Discrep	.18	0.10 (0.14)	0.53	.62	0.09 (0.05)	1.67	.16

† Task administered at age 9 years

As a conservative estimate, VT's quality of artwork would be considered at least talented when utilising Treffert's savant categories.

Consistent with his diagnosis, ratings from a parent-report screening tool assessing VT's current and historical behaviour (SCQ) fall within the range indicative of an ASD. VT's overall IQ score fell in the borderline range. His nonverbal IQ was 11 points higher than his verbal IQ, but still approximately one standard deviation below the norm for his same-age peers. The profile of scores within the verbal domain was relatively flat with a high on Similarities and a low on Information. The most extreme subtest scores were contained within his nonverbal IQ profile, which included a high score on the Block Design task, a prototypical result for individuals with ASD, and a low on Coding. Since it is safe to assume that the low score on the Coding subtest does not reflect any graphomotor difficulties, this finding may suggest a deliberate, methodical style, particularly when asked to draw even the simplest shapes, as required by the Coding task.

As predicted, and consistent with anecdotal reports of his "eye for detail", VT demonstrated a pattern of results consistent with a weak drive for central coherence, especially when compared to the performance of the individuals with TD/MLD. To this end, in addition to a relatively high Block Design score, VT was faster and more accurate than the TD/MLD comparison group when asked to locate embedded figures (in spite of his younger age at the time of assessment). Moreover, he provided a greater number of local completions on the sentence completion task and a lower percentage of global matches on the Navon-type task. These findings converge in implicating a piecemeal approach by VT when processing novel data. However, though VT was more accurate than both comparison groups in identifying im/possible figures, these differences did not reach statistical significance.

Particularly good performance on the second half of the statistical learning task, as demonstrated by proportional RT gain, was shown by VT. His RT gain was significantly (one-tailed) better than that of matched controls and approached significance (one-tailed) when compared to the mean score of the ASD controls. This provides some support for superior implicit learning in the visuospatial domain.

VT's memory, as assessed by performance on a visuospatial recognition task, fell in the superior range. His score was a full three standard deviations above the mean for his same-age peers and far out of line with expectations based on his IQ. This excellent performance on a standardised task, a rarity for savants, is keeping with anecdotal reports of the eidetic-like quality of savant memory, particularly amongst artists. Also assessed was his ability to understand spatial relations when presented with meaningless, abstract shapes. Again, VT performed well, scoring one standard deviation above expectations based on his age and much better than predictions based on his IQ level. These findings likely indicate the importance of both basic visual memory and understanding of spatial relations in artistic skill expression.

VT's performance on tasks of time perception was generally commensurate with means from both comparison groups, though his time estimation ratio score was notable for reflecting an underestimation, inconsistent with findings observed in the control groups and in the group studies reported in Chapter 6. Furthermore, a non-statistical within subject ("eyeball") comparison revealed fairly consistent scores across the time perception tasks, which again contrasts with findings from the control groups and those from the earlier reported group studies.

Together these findings indicate that VT demonstrates clear WCC, good implicit learning, superior visual recognition memory, and good understanding of spatial relations within objects; all of which may contribute to VT's outstanding artistic ability.

8.5 Case 2: NC

8.5.1 Description

At the time of testing, NC was an 11-year-old boy with Asperger's syndrome. He was eager to share his interests, particularly in machines and computers, with the examiner.

NC's family history for ASD and other difficulties was unremarkable. NC was diagnosed with Asperger's syndrome at the age of 5 years and he currently displays many prototypical behaviours. For example, his mother describes his conversations as sometimes one-sided and centred on his interests (e.g., electronics). He is also described as getting on better with older children than with children his own age, because of shared interests, though he does not have a best friend.

The examiner spent approximately four hours with NC. NC was both very responsive and attentive during the testing session. However, after testing was completed, NC had what could be described as a "meltdown". The excellent concentration and attentiveness he had displayed earlier were replaced by behavioural outbursts, such as running around screaming and goading his sister. NC's mother expected this reaction and attributed it, at least partially, to his difficulty with transitions.

8.5.2 Special Skills

NC came to the examiner's attention because of his participation in a previous study for which Dr. Francesca Happé was the Principal Investigator. It had been reported that NC had created his own miniature refrigerator from spare parts of other machines and that he was fascinated with all types of machines and the way they work. His mother reported that a few months prior to the testing session, NC's parents had to remove covertly the accumulated mass of electronics, machine parts, and other similar items that had simply overwhelmed his bedroom. NC was upset over this removal, but understood why it had been done.

NC's mother reports that NC is completely fascinated with electronics/electrical items and how they work. As part of the visit, the examiner had NC diagnose the problem(s) with a broken fax machine. He was thoroughly excited to accept this challenge and demonstrated extraordinary levels of concentration and attention during this task. He provided commentary as he meticulously took apart the fax machine. After approximately forty minutes, he accurately diagnosed the difficulty as a "fried" circuit board due most likely to a power surge. The owner of the fax machine reported a power outage and surge around the time the fax machine stopped working.

Perhaps most salient and unique to this case, as compared to the other three reported here, was NC's true absorption in his area of interest. He was truly fascinated with machines, computers, and other electronics/electrical items. As discussed in the introduction to Chapter 8, this area of interest has long been reported by individuals with ASD and their caregivers.

After testing NC, his skills and capabilities were described to an experienced engineer, who found them to be exceptional given NC's age and functioning level.

8.5.3 Results and Interpretation

Clinical Measures:

WISC-III (Administered in 2000; see Figure 8-3)	
FSIQ:	100
VIQ:	96
PIQ:	104

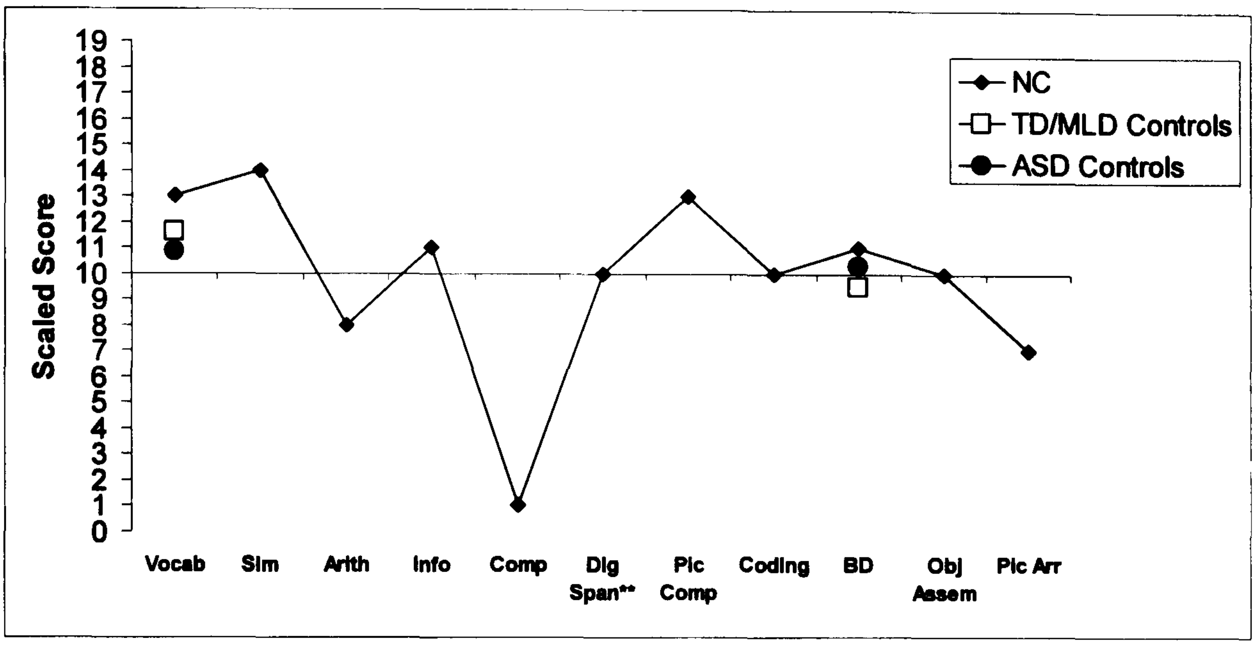


Figure 8–3. Profile of NC's IQ Scores.

** - supplementary subtest not utilised in the calculation of FSIQ, VIQ, or PIQ

SCQ	
Total	30
Social	13
Communication	10
Repetitive Behaviours	7

Experimental Measures

Table 8-3 presents IQ and experimental task results for NC as well as those of his two comparison groups. NC's IQ, EFT, and sentence completion data were obtained in the context of another study conducted by Dr. Happé and colleagues. The age at which these tests were administered is noted below.

Table 8–3. Performance on Tasks Administered to NC and Matched Controls: Mean (SD).

Measure	NC	TD/MLD Control Group (n=12)	t	*p*	ASD Control Group (n=6)	t	*p*
Age	11.08	11.50 (0.54)	0.74	.47	11.71 (1.15)	0.51	.63
FSIQ†	100	103.33 (9.06)	0.35	.73	103.67 (17.92)	0.19	.86
Vocabulary	13	11.58 (1.78)	0.77	.46	10.83 (2.32)	0.87	.43
Block Design	11	9.50 (2.35)	0.61	.55	10.33 (2.66)	0.23	.82
EFT†							
% Corr All	67	73 (20)	0.29	.78	82 (14)	0.99	.37
Avg Time All	33.67	24.99 (9.70)	0.86	.41	21.18 (9.69)	1.19	.29
% Corr Adult	63	53 (32)	0.30	.77	75 (24)	0.46	.66
Avg Time Adult	30.38	37.47 (14.90)	0.46	.66	23.60 (15.51)	0.40	.70
Implicit Learning							
Prop RT Gain between 1st & 2nd Halves	.03	.10 (.13)	0.52	.62	.08 (.10)	0.46	.66
Prop RT on 2nd Half	.08	.08 (.08)	0	1	.08 (.07)	0	1
Sentence Comp†							
No. of Loc Comp	2	0.42 (0.67)	2.27	.04	1.17 (0.98)	0.78	.47
Im/Poss Fig Cat							
No. Corr Poss Fig	10	8.33 (1.15)	1.40	.19	7.67 (1.37)	1.57	.18
No. Corr Imp Fig	10	7.00 (1.35)	2.14	.06	5.67 (2.42)	1.66	.16
Avg RT to Corr Poss Fig	1531	2091.50 (489.14)	1.10	.29	1432.50 (292.90)	0.31	.77
Avg RT to Corr Imp Fig	2236	2630.75 (745.28)	0.51	.62	1835.67 (304.79)	1.22	.28
IT	56	50.17 (34.20)	0.16	.87	42.00 (8.43)^	1.52	.20
Folk Physics	75	63.57 (18.19)⌂	0.59	.58	NO DATA		

† Tasks administered at age 8 years

^ n=5

⌂ Data from TD Adults (n=7)

Based on feedback from an experienced engineer, NC's mechanical skills certainly would be considered talented.

SCQ scores, based on parent report, were compatible with NC's diagnosis, with difficulties in all three aspects of the "triad of impairment" that characterise autism.

NC's IQ was overall solidly average. Of the verbal subtests, there was a peak on the Similarities subtest, which requires one to describe how two words are conceptually similar, and an outlying trough on the Comprehension subtest, which aims to measure understanding of real-world rules and social convention. Among the nonverbal subtests, he obtained his highest score on Picture Completion, which requires the identification of a missing element in a drawing, and his lowest score on Picture Arrangement, which requires arranging "snapshots" of a sequence of events (including some on social themes) in their proper order. Given his diagnosis, it is unsurprising that NC received his lowest scores on the two subtests with perhaps the greatest reliance on social knowledge.

Consistent with predictions based on the WCC theory and with previous findings (Happé & Booth, in preparation), NC demonstrated a tendency to complete unfinished sentences read aloud to him with local endings. He produced significantly more local completions than did the TD/MLD control group, but his performance was within one standard deviation of the ASD control group's. On the EFT, NC's performance was roughly comparable to that of both control groups; however, at the time of testing, he was three years younger than the average age for each of the control groups to which he was compared. Therefore, the lack of a group difference on this test may be misleading, since he was put at a disadvantage, given significant positive correlations between age and EFT performance amongst TD children. When asked to identify im/possible figures, NC exhibited perfect accuracy, which was better than both the age, gender, and IQ matched controls and the matched ASD controls, though these differences were not statistically significant. As indicated from correlational analyses in Chapter 6, performance on this task may more accurately reflect general nonverbal ability rather than WCC, hence NC's good performance.

NC's difference score of RT gained between the predictable shape sequence and unpredictable shape sequence was comparable to that obtained by the control groups (and results from the group study reported in Chapter 6), indicating intact implicit learning. Similarly, NC's IT did not differ significantly from that found in the two control groups. Unlike the predicted superiority, these findings may support a "gateway" model to savant skill development.

Though age and/or diagnosis matched controls were not given the Folk Physics Test, NC's performance on this task was in line with that of the TD adult control group (matched to the two adult savant cases), composed of males considerably older and with more real-world experience from which to draw possible conclusions. NC's good performance on this test is consistent with a previous report of better folk physics performance (systemising) amongst children with ASD than amongst TD children (Baron-Cohen et al., 2001).

Given his good performance on the Folk Physics Test and his keen interest in machines and electronics, it seems that NC's mechanical skills are derived from a combination of good aptitude and high levels of motivation, a mixture often invoked to explain skill acquisition observed in TD individuals with various talents and from wide-ranging professions.

8.6 Case 3: MG

8.6.1 Description

MG presented as a mellow and friendly man who was eager to share his recent experience exhibiting artwork in New York City and elsewhere and his recent acceptance to have his artwork exhibited in London. During testing, MG was very well engaged and very compliant.

MG is a right-handed 42-year-old, single male who was diagnosed with Asperger's syndrome in 2001 upon referral to a diagnostic clinic in the Boston metropolitan area. He was relieved to have obtained the Asperger's syndrome diagnosis, given his past difficulty with holding down jobs and his understanding that he enjoyed talking endlessly about certain topics (e.g., art), while others' attention was not consistently captured by the same subject matter. Despite the diagnosis of Asperger's syndrome as an adult, MG reports a significant delay in the acquisition of language, stating that he did not talk before the age of three years and in fact, he would "point and grunt". Before the age of six years, he described his speech as "baby talk". As a child it was suspected that he had autism because of his rocking and difficulty relating to others. Moreover, he reports a fascination during early childhood with the smell of a particular type of vacuum cleaner, which contained crystals with a distinct odour. He also reported early difficulties with behaviour (i.e., he had frequent temper tantrums) and with learning. He described himself as a visual learner and stated that whenever he was required to learn by only listening, he retained and understood much less than when visual aids were given. He also reported problems with mathematics, although he enjoyed multiples of two and for pleasure would occasionally take the time to fill an entire page with multiples of two. MG was removed from the care of his mother at the age of 12 years because of potential neglect and was subsequently raised by an aunt until he was 17-years-old. He then spent four years in the military and reported this as a positive experience; he received an honourable discharge. He noted that the regularity and structure of the military life allowed him to thrive. He then started taking classes at the University of Texas in Austin. For the first semester he was a full-time student, but during the second semester he struggled to complete his work because of an increasing depression. Eventually this depression led to hospitalisation in a Texas state hospital.

MG had a six week stay in the Texas state hospital where he was placed on lithium and Thorazine. After this hospitalisation, he moved to Tennessee where he worked with and stayed with a family friend for seven years. During this time, he would save up enough money from working odd jobs, like construction, in order to take trips to Europe where he would devote himself to his art. His last hospitalisation occurred in Tennessee, near Knoxville, in 1998, when his medications were Depakote and Risperidol. He reports that he has not come close to "sinking that low" since and that he feels very well adjusted compared to the past; he is not currently taking any psychiatric medications. He currently resides with a roommate in a rent-controlled apartment.

Family History

MG is the fourth of six children, all of whom are half siblings. MG is not the only member of his family with a history of developmental difficulties and/or special talents, since, for example, an uncle and cousin were thought to have both intellectual impairments and special skills. Both of his relatives with savant-like skills were raised in rural Appalachia, given the label of "mental retardation" and were nonverbal. The uncle was gifted with numbers and the cousin had remarkable mechanical aptitude. Moreover, another cousin has been diagnosed with autism and MG's mother may have had learning difficulties. As mentioned earlier, his mother was declared "mentally incompetent" leading to his living with an aunt from ages 12-17 years. MG's mother is also suspected of having alcohol and other substance abuse problems. Although MG reports that she drank during her pregnancies, he is not aware of any child in his family receiving the diagnosis of foetal alcohol syndrome or demonstrating foetal alcohol effects.

8.6.2 Special Skills

Development and Current Level of Calendar Skill

MG demonstrates ample calendar calculation ability. Unusually, MG was not very interested in calendars as a child, but instead developed these abilities as an adult. However, MG reports that at age five or six years, he remembers seeing his grandmother's calendar and "knowing" dates for "only a couple of years". At 17 years of age, MG made his first drawing of calendars, when he still "only knew a couple of years".

Then, when MG was approximately 32-years-old, he began calendar calculation of a greater range. Interestingly, when MG learned about Asperger's syndrome, he realised that his interest in calendars had always been there, but he had not pursued it. He then began exploring it further. He started thinking about it more and "let it happen". Numbers have always come into his head, but he would not "think" about it. MG reports that during periods of significant withdrawal in his life, the calendar calculation would really exhibit itself. Like other calendar calculators, he cannot tell you precisely how he does it, but he "just knows" the answer and it usually "feels right". Although MG is not flawless in his calendar calculations, his performance does not seem to vary considerably based on temporal distance from the present. Indeed, his calendar range is practically endless; in the context of this case study, the years tested ranged from 1591-8378.

Development and Expression of Art Ability

MG reports that he has been drawing "as long as he can remember" and has always excelled in this endeavour. As a young child, his drawings were usually focussed on a single object, yet later his subject matter broadened in scope. According to MG, he was almost always considered the best drawer in his class throughout his school years.

MG demonstrates a unique artistic perspective. His artistic style has changed over time, going from more stereotypical savant art in his adolescence and early adulthood, including drawings of scenes and buildings, to more abstract impressionist style paintings as a young adult and then back again to technical type drawings of real and/or imaginary machines, for example, though with more stylistic elements included. In order to save money, he often uses thick napkins, stains them with coffee to give them a weathered look, and then proceeds to draw mechanical designs (either contrived or based on real designs), buildings, or any number of other recurring subjects (e.g., satellite photos of the earth, fossils, etc.). He also currently creates magic calendar squares which are based on the principle that any way you look at the rows, columns, or diagonals, they will always "add up" or result in the same answer. This has been demonstrated with large numbers, but MG is the first to apply this to the calendar. He has been in email correspondence with the foremost expert on magic squares, Walter Trump, who currently resides in Germany. Moreover, he has attracted interest in his current work from a gallery in London (MG currently lives in a Mid-Atlantic state of the USA), which agreed to exhibit a large body of his work during the fall of 2004 and spring of 2005. He also had a very successful exhibition at the 2005 Outsiders Art Fair in New York City resulting in a number of sales and requests for commissioned artwork.

Two art judges, one of whom has previously judged art for competitions and the other who has experience not only as a judge, but also as a curator, were recruited to evaluate the artwork of the two adult savants with artistic skills. Both of the judges were particularly high on MG's work and style. Without hesitation, they favourably compared MG's work to that of other contemporary artists who both exhibit widely and are very successful in selling their work.

For examples of MG's artwork, refer to Figure 8-4 below and to Appendix D.

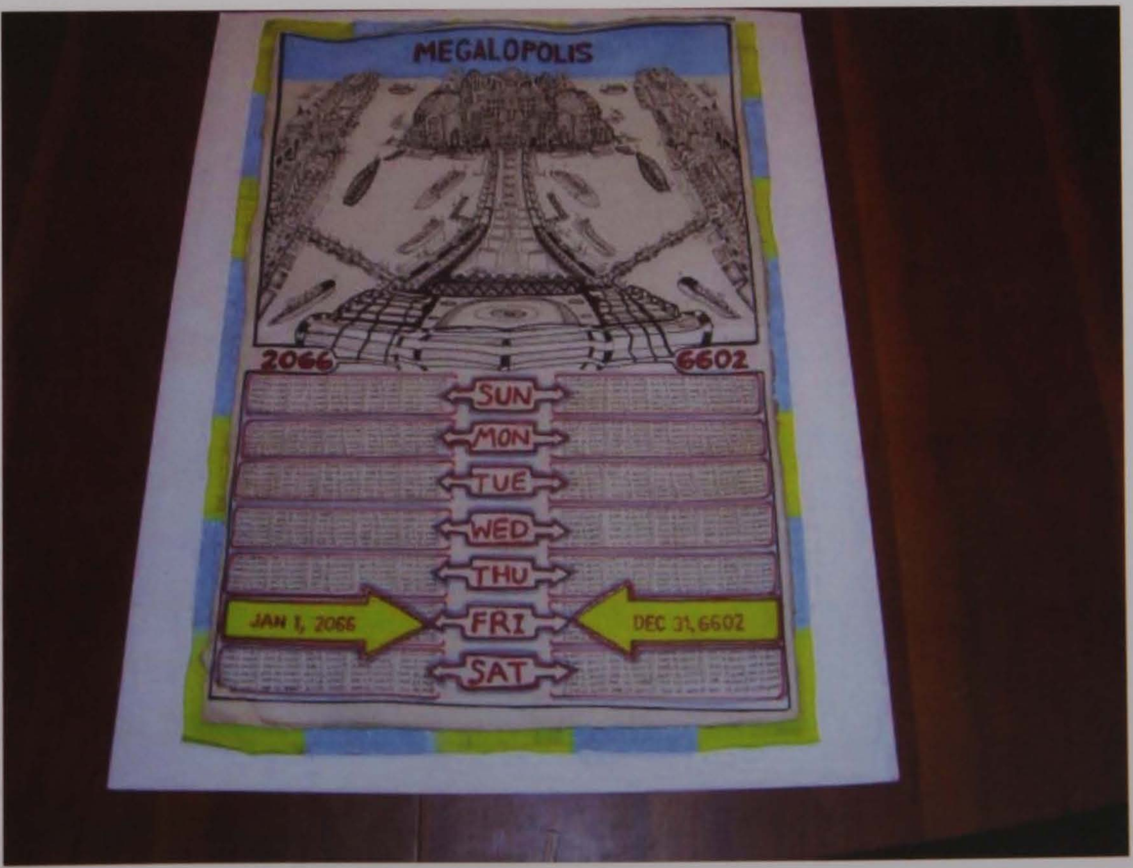


Figure 8–4. Example of MG's Artwork.

8.6.3 Additional Methods

A number of the following tests (i.e., the WRAT-3, Wisconsin Card Sorting Test, ROCF, and Hooper Visual Organisation Test) were administered previously to MG in the context of a clinical evaluation.

Graded Difficulty Arithmetic test (GDA) (Jackson & Warrington, 1986) – For this task, the participant is asked to rapidly (within 10 seconds) answer 12 addition and 12 subtraction problems varying from two digit +/- one digit numbers to three digit +/- three digit numbers without the use of paper and pencil.

Wide Ride Achievement Test-3, Arithmetic Subtest - The purpose of the Arithmetic subtest from this well-standardised assessment tool is to measure basic mathematical skills. The participant is asked to calculate simple to more complex mathematical problems ranging from basic mechanics to algebraic equations. The participant is allowed the use of paper and pencil. No partial credit is given, nor is the scoring based on speed.

Wisconsin Card Sorting Test (WCST) – This test assesses flexibility in shifting cognitive set. The participant is asked to sort each card according to one of three dimensions (colour, shape, or number) that must be deduced based on feedback. Once the "rule" has been deduced, the participant must maintain sorting on this dimension for 10 trials in order to receive credit for having achieved this category. Indeed, the two main indices of performance are categories achieved and perseverative errors. Perseverative errors result from erroneous sorting along one dimension despite feedback indicating that this dimension is incorrect.

Judgement of Line Orientation – This task is a measure of spatial perception. The participant is presented with a pair of line segments followed by 11 numbered radii forming a semi-circle. The participant is asked to match the pair of line segments to two of the 11 numbered radii. Performance is based on accuracy in identifying the corresponding number to each line segment.

ROCF – Participants are asked to copy this meaningless complex figure with the original figure remaining in full view. Approximately 20 minutes later, the participant is asked (without prior knowledge) to recall the figure and draw it as best they can from memory. The figure is scored quantitatively for accuracy in global and local elements recalled and qualitatively in terms of the participants' general approach to the figure.

Hooper Visual Organisation Test – Thirty pictures of generally recognisable cut-up objects are shown to the participant and s/he is then asked to verbally name each of these objects. Performance is based on accuracy in identifying these objects.

Calendar Performance (Cowan et al., 2003) – General calendar performance in terms of accuracy and RT over a large span of years in the Gregorian calendar (a total of 90 items) was assessed along with some late years from the Julian calendar (25 items). Calendar knowledge was also assessed by having MG calculate the day on which two identical dates from different years fell; in one condition the dates shared the same calendar template (e.g., 5 April 2005 and 5 April 1994) which should result in faster RT on the second date if (implicit or explicit) knowledge of this template was used as a strategy, whereas in another condition the dates were from two different calendar templates (e.g., 5 April 2005 and 5 April 1990), which should result in no RT savings. Priming was therefore assessed and operationalised through calculation of a percentage savings score.

8.6.4 Results and Interpretation

Clinical Measures:

WAIS-III (see Figure 8-5)	
FSIQ:	100
VIQ:	98
Verbal Comprehension (VC): (Vocab + Sim + Info)	100
PIQ:	104
Perceptual Organisation (PO): (PC + BD + Matrix)	116

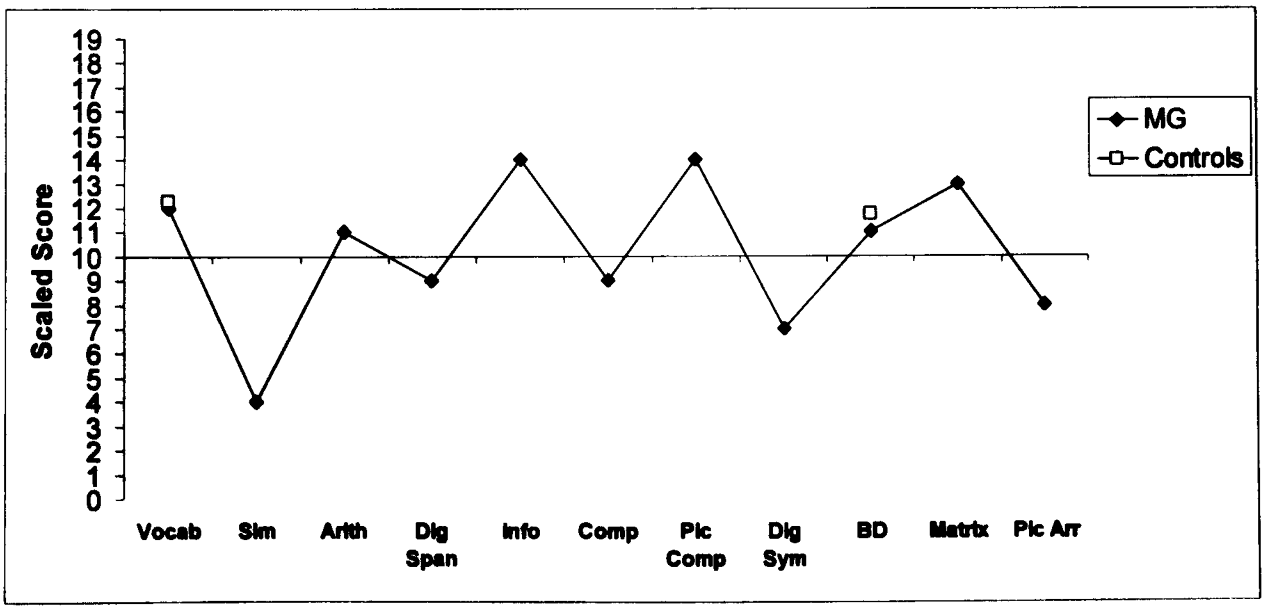


Figure 8–5. Profile of MG's IQ Scores.

WJ-R		SCQ	
Picture Recognition	111	Total	28
Spatial Relations	113	Social	13
		Communication	6
		Repetitive Behaviours	9

GDA –MG correctly answered 21 of the 24 items administered in the allotted 10 second span. This translated to a scaled score of 16, which fell in the superior range.

Wide Range Achievement Test-Arithmetic Subtest – MG obtained a score of 110, which is slightly above average, equal to the 75th percentile, and equivalent to post-high school levels of education.

Wisconsin Card Sorting Test – MG exhibited a bit of difficulty when completing this task of set-shifting ability. He was able to utilise feedback to shift problem-solving sets, but he sometimes "lost set" and then became fixated on matching sets by colour.

Judgement of Line Orientation – On this task of spatial perception, MG obtained a standard score of 102, which fell in the solidly average range.

ROCF – MG adequately copied this complex yet meaningless figure; however, when asked to recall the figure approximately 20 minutes later, his strategy was fragmented leading to a disorganised figure. His performance at recall fell in the bottom 10% of performance on this task for comparably aged TD adults.

Hooper Visual Organisation Test – MG excelled at identifying objects based on line drawings of their parts, correctly identifying all 30 items.

Experimental Tasks and Questionnaires

Table 8-4 presents IQ and experimental task results for MG as well as those of his comparison group.

Table 8–4. Performance on Tasks Administered to MG and Matched Controls: Mean (SD).

Test	MG	TD Control Group (n=7)	t	*p*
Age	42	40.68 (7.45)	0.17	.87
FSIQ	100	111.57 (11.80)	0.92	.39
Vocabulary	12	12.29 (3.40)	0.08	.94
Block Design	11	11.71 (1.60)	0.42	.69
EFT				
% Corr All	93	86 (10)	0.65	.54
Avg Time All	9.07	19.59 (7.40)	1.33	.23
% Corr Adult Items	88	77 (17)	0.60	.57
Avg Time Adult Items	13.25	27.44 (10.40)	1.28	.25
Implicit Learning				
Prop RT Gain between 1st & 2nd Halves	.10	.06 (.18)	0.20	.85
Sentence Completion				
No. of Loc Comp	0	0.29 (0.49)	0.55	.60
Im/Possible Figure Categorisation				
No. Corr Poss Fig	9	9.00 (0.63)	0	1
Avg RT to Corr Poss Fig	3468.33	2020.68 (994.59)	1.35	.24
No. Corr Imp Fig	9	8.50 (1.97)	0.24	.82
Avg RT to Corr Imp Fig	2661.67	2077.88 (657.82)	0.82	.45
Time Perception				
Time Est Ratio	1.44	1.02 (0.15)^	2.59	.05
Time Prod Ratio	1.45	0.97 (0.19)^	2.34	.07
Time Rep Ratio	0.99	0.93 (0.07)^	0.79	.46
Time Est Discrepancy Score	0.44	0.13 (0.06)^	4.78	.004
Time Prod Discrepancy Score	0.45	0.15 (0.11)^	2.53	.05
Time Rep Discrepancy Score	0.01	0.09 (0.04)^	1.85	.12
IT	39	33.43 (8.54)	0.61	.56
Folk Physics % Correct	55	63.57 (18.19)	0.44	.67
EQ	21	42.14 (15.49)	1.28	.25
SQ	33	24.86 (9.96)	0.76	.47

AQ Total	47	13.57 (4.65)	6.72	.0005
AQ Social Skills	10	2.29 (2.69)	2.68	.04
AQ Attention Switching	9	3.43 (1.81)	2.88	.03
AQ Attention to Detail	10	4.57 (1.13)	4.50	.004
AQ Communication	9	0.86 (1.07)	7.12	.0004
AQ Imagination	9	2.43 (1.81)	3.40	.01
Adult Sensory Profile				
Sensory Sensitivity	65	29.17 (8.80)^	3.77	.01
Sensation Avoiding	64	31.33 (6.25)^	4.84	.005
Low Registration	53	30.67 (6.15)^	3.36	.02
Sensation Seeking	34	45.50 (8.34)^	1.28	.26

^ n=6

Calendar Performance

Overall Performance:

24/26—92.3% range of tested dates: 1828-1836 and 2017-2024

33/39—84.6% range of tested dates: 1772-1777 and 2072-2165

24/25—96% range of tested dates: 2363-8378

Performance on Dates Preceding the Gregorian Calendar:

When asked to answer calendar questions from the Julian calendar (although not explicitly labelled as such) ranging from 1591 to 1751, MG obtained a mark of 21/25, with one of the errors a correct answer if based on the Gregorian calendar. Therefore, his performance on these dates is either 21/25=84% or 22/25=88%.

Priming Study:

MG saved just less than one second per pair (0.83 sec/pair or 15 seconds across 18 pairs); though this is a small amount, the baseline RTs were very fast. In other words, there was not a great deal of room for improvement---48 total seconds on initial items in pairs, amounting to a savings of 15/48 = .3125 or 31.25% savings, which is a relatively large savings score and evidence of "priming" based on knowledge of calendar regularities.

MG presents as an interesting case study for at least two reasons: 1) he demonstrates at least two savant skills, both artistic skill and calendar calculation ability (which may also include superior mnemonic skill in the domain of number and good to excellent mental calculation ability) and 2) he traces his own skills to those in an uncle and a cousin who were both "savant" in the classic sense.

Applying Treffert's (1989) criteria, MG's easily quantifiable skill, calendar calculation, was exceptional or "prodigious," even by calendar savant standards, given the range over which he was tested and the speed with which he gave responses. Moreover, the two art judges enthusiastically endorsed MG's artistic abilities as in line with that of professional artists who regularly exhibit in the community.

Consistent with his diagnosis, MG rated himself as having assets and difficulties (particularly in communication) characteristic of autism as measured by the AQ. Moreover, results from his sister's ratings of MG on the SCQ indicate that his historical data fit with a diagnosis on the autism spectrum. MG's IQ profile demonstrates great subtest scatter with the highest scores on Information and Picture Completion and the lowest score on Similarities. Overall his general, verbal, and nonverbal IQs fell in the average range, but this can be misleading given his range of strengths and weaknesses on the tests comprising these general indices. However, there was a clearer discrepancy when utilising the PO and VC indices; his PO score is more than one standard deviation higher than his VC score, even though the latter is solidly average. This magnitude of discrepancy in the standardisation sample for the WAIS-III is fairly unusual ($p<.01$), reinforcing its potential significance. Given the juxtaposition of his disability with his medium of choice (i.e., visual art), discrepantly high visuospatial abilities are not terribly surprising. Furthermore, this relative strength was corroborated on two further tests of spatial perception and ability. On the judgement of line orientation task, his score was solidly average, while his score on a task requiring him to identify the component parts of larger, abstract shapes was above average.

This association between good visuospatial abilities and savant skills may hold regardless of skill domain. For example, Heaton et al. (1999) found that the subgroup of musically naïve children with autism who had good performance on tasks of musical cognition exhibited good visuospatial abilities on IQ tests in a similar fashion to MG's results. However, one instance of good verbal skills contributing to savant skill performance was noted in the domain of calendar calculation (Rumsey et al., 1992), particularly correlating to the range over which a savant might accurately predict the day of the week on which a date falls. In this case, the correlation with verbal ability might reflect top-down influences, contributing specifically to strategy usage, not necessarily to the development of the skill. In other words, it is unlikely that verbal ability constitutes a core underlying mechanism of the skill.

MG scored in the average to above average range on a measure of written arithmetic. However, in comparison to the GDA (mental calculation) performance of Jackson and Warrington's (1986) 100 control participants (a portion of whom were "patients with extra-cerebral neurological disorders"), MG's total score was equal to or greater than that of 99 of the controls. It is thus concluded that a significant component to MG's superior calendar calculating ability, especially his extraordinary range, is good, rapid mental calculation ability. Indeed, Cowan and colleagues (2003), utilising the same task (i.e., the GDA), found that three of 10 calendar savants performed at superior levels when compared to the same standardisation sample. Furthermore, Rumsey and colleagues (1992) found, when utilising a novel mental arithmetic test, that calendar calculation performance and range among a sample of 11 savants were related to their ability to perform mental calculations of similar difficulty.

Memory has been implicated in calendar calculation and other savant skills. Here it was assessed with a simple and standardised visuospatial recognition task. MG performed in the average to above average range on this task, roughly commensurate with his overall IQ. Nevertheless, as has been previously mentioned, very rarely do savants obtain very high scores (case VT not withstanding) on these types of standardised tasks. For example, in MG's case, there is anecdotal evidence that his memory, especially for numerical information, is particularly good. As an illustration, he recently memorised the exact populations for hundreds, perhaps for more than a thousand, cities in the United States of America, based on the latest Census data. When I informally questioned him on 50 randomly chosen cities (populations varying approximately between 10,000 and 10 million individuals), MG did not miss a single digit amongst these population values.

Hermelin and O'Connor (1986) documented the use of two rules in their group of eight savants, the corresponding months rule and the 28-year rule. The Gregorian calendar contains regularities (although not completely lawful) that may facilitate calendar calculation, such as the same day-date correspondence within certain corresponding months within a calendar year or the repetition of the calendar template every 28 years. To demonstrate the use of these rules, Hermelin and O'Connor (1986) examined the RT of subjects when primed with dates in corresponding months. If they were indeed faster on the date from the second of a pair of corresponding months, it could be assumed that they were utilising this rule to facilitate speed and performance. Here, a priming study was completed to assess MG's potential knowledge of calendrical regularities. Instead of relying solely on a particular rule, such as the 28-year rule, this task assessed whether a similar calendar template would result in faster performance when presented two times in a row. So, when asking the day of the week on which the same month and day (e.g., March 14th) fall, but in different years (e.g., 1985 and 1991) the second item should be responded to more quickly. Since MG was unable to communicate how he performed calendar calculations, inferences concerning his calendar knowledge were necessary. A difference in speed of calendar calculation, expressed as a savings score, was demonstrated between those (pairing of) items where the same calendar template could be utilised and those where it could not. This directly corroborates Hermelin and O'Connor's (1986) finding that calendar-calculating savants utilise a rule or regularity of calendar structure for completion of this task. Moreover, indirect documentation of calendar knowledge by MG importantly demonstrates that his calendar skills are not simple memory feats. Indeed, taken together with MG's good mental calculation abilities, it is clear that MG's skills are in line with other researchers' (Hermelin & O'Connor, 1986; Howe & Smith, 1988) hypothesis that calendar savants may rely on both memory and rule-use in their calendar calculation, with idiosyncratic degrees of reliance on each, while good calculation abilities may serve to extend their calendar range well into the future.

As opposed to MG's seemingly flexibly accessed calendar knowledge, when presented with cards and asked to sort them along various dimensions based on examiner feedback, he often demonstrated perseveration and an occasional inability to maintain a problem-solving set. In fact, to MG's credit, he was aware of his perseveration, noting that he often does this in everyday behaviour, doing something over and over again, yet he is unable to alter his behaviour. Compromising MG's flexible approach to the calendar and to art (given the various styles and techniques he has used, unlike many other savant artists) with this finding of difficulties on a task tapping a "domain general", executive process is difficult. However, this may provide clues as to the architecture and interactions of modular and domain general mechanisms operating in cognition.

Based on the profile of experimental test results, there is evidence to suggest that MG demonstrates WCC. He was faster in finding hidden shapes in the EFT than were matched controls; however, this difference failed to reach statistical significance. When MG was asked to copy and later recall a novel but nonsense figure, MG utilised a piecemeal approach, similar to the graphic savant described by Mottron and Belleville (1993), drawing elements one at a time, rather than starting with large portions of the figure and working towards more detailed elements of the figure. Moreover, when asked to identify an object based solely on viewing component pieces, MG exhibited perfect, ceiling-level performance. In an extension to everyday behaviour, MG rated himself much more attentive to detail than did the matched controls in the context of the AQ. However, MG performed comparably to the matched control group when asked to identify im/possible figures and he did not provide local sentence completions when asked to complete an unfinished sentence. For this latter task, given the very low frequency of local completions provided by MG, case NH, and the members of the adult control group, the lack of a finding likely reflects this instrument's lack of sensitivity within an adult age range, rather than good global processing.

Interestingly, on both indices of performance on the time estimation and time production tasks, MG scored significantly worse than did matched controls. In contrast, and similar to findings from the group studies reported earlier, MG's time reproduction performance was either comparable to or better than that of matched controls, depending upon the index utilised. As mentioned previously, after quizzing MG on the population of approximately 50 different cities, he had yet to incorrectly identify a single city's population. Given MG's excellent memory ability as exemplified by the Census information, it may be that information (whether populations or "time" from the time reproduction task), once encoded, degrades at a much slower rate for MG than for other TD adults.

MG's performance on the implicit learning and IT tasks was comparable to that of the control group, fitting the profile of performance observed for case NC and the group study results reported in Chapter 6. Again, these intact, not superior cognitive processes in MG's profile, fit a model indicating that they may provide a "gateway" to savant skill development.

MG's grasp of naïve or intuitive physics is also commensurate with that of gender, IQ, and age matched controls. Given his (relatively recent) interest in contrived machines and buildings, this is a bit surprising. Nevertheless, his interest appears to lie in the look and design of machines rather than in the way they operate or work. MG's systemising quotient paralleled his folks physics test performance since it was also comparable to scores obtained by the matched control group. Though not statistically significantly different, MG's empathising quotient was half as high as the score obtained by the matched control group. MG's performance on these two questionnaires was notable, not because of the absolute scores, but because of the pattern of scores. What is clear is an opposite pattern of scores for the case versus the controls; MG scored higher on the systemising than the empathising quotient, mirroring what is seen in the matched control group.

Based on self-report from the Adult Sensory Profile, compared to matched controls, MG exhibited significantly greater sensory sensitivity and avoidance along with lower sensory registration. However, in spite of this, MG's tendency to seek out sensory experiences was not significantly different from the matched controls'. On each of these four indices, categorical ratings were extreme for MG, so that his score was considered 'very high' for sensory sensitivity, sensation avoiding, and low registration, while his score for sensation seeking was considered 'very low'. As a contrast, none of the matched controls were rated as 'very high' or 'very low' on any of these indices, save one participant who also received a rating of 'very low' on the sensation seeking index.

In summary, findings from studying MG's calendar calculation implicate the influence of good memory, some knowledge of calendar templates, and good mental calculation ability as contributory. More generally, in MG's neuropsychological profile, there were consistent indications of WCC, intact implicit learning and IT, and relatively good time reproduction, all of which may be related to his multiple savant skills.

8.7 Case 4: NH

8.7.1 Description and History:

NH presented as a pleasant 44-year-old right-handed male who was eager not only to participate in research, but also to answer questions regarding his drawings and artistic skills.

According to self-report, NH did not exhibit any remarkable early developmental illness, injury, or trauma. Birth weight was within the average range and there were no reported abnormalities during the pre-, peri- or post-natal periods. Indeed, consistent with his diagnosis of Asperger's syndrome, his parents did not exhibit concern over his attainment of early cognitive and language milestones. Moreover, according to NH, throughout his school age years, there seemed to be no cause for concern on the part of NH or his parents in regards to his social and cognitive development and his academic achievement. Initial issues arose during his college years. NH first learned of classical autism from a television program in 1988, but he did not think this label fit his own experiences. However, upon reading *Nobody Nowhere* by

Donna Williams in 1992, NH became convinced that he was an undiagnosed case of Asperger's syndrome. He then wrote to an Asperger's syndrome expert and experienced clinician in London in order to participate in the diagnostic process and obtain a specialist's opinion; however, two stumbling blocks surfaced. First, when the idea was brought up to his GP, NH was discouraged because the GP, using parameters of classically defined autism, felt NH did not exhibit these behaviours. Secondly, in the midst of his correspondence with the expert clinician, NH requested to keep his parents out of the diagnostic process both due to his "self-reliance and pride", as he puts it, and because of what he perceived as apathy on the part of his parents. According to NH, this expert clinician maintained that his parents must be involved in the process. Finally, three and a half years subsequent to his reading of *Nobody Nowhere*, NH underwent a diagnostic evaluation in London, which led to the diagnosis of Asperger's syndrome in January 1996.

During general questioning of NH, some symptoms indicative of individuals with ASD were reported. For example, NH reports that he continues to have sensory sensitivity to some noises and textures as well as to temperature while eating. At various points during his adult years, he reports becoming all-absorbed in his art and hoarding things, like jam jars and newspapers; this latter tendency to hoard things is also reported for his father, the only indication of some family history of ASD traits.

8.7.2 Special Skill:

NH says that he has "always had a talent for art" and that one of his earliest memories pertains to success in this domain. At nursery school, at approximately three years of age, NH recalls his teacher requiring the children to draw a snowman. After NH had finished his drawing, his teacher commented on how exceptional she felt his drawing was and indeed shared this with NH's parents. NH did not receive specialised training in art during his primary or secondary school years; however, in 1975-1976, at the age of 16 years, he attained a C.S.E.-1 in art. Since school ended, among other subjects, he passed Geometric and Mechanical Drawing at Ordinary Level and Art at Advanced Level, while also obtaining a Pass with Merit in Precision Model-Making as part of his Higher Diploma in Applied Design. Subsequently, he spent 14 years in model-making, predominantly architecture.

Currently, he draws primarily with felt-tipped pens. NH reports that in the past he has liked drawing in biro and making robots out of legos and skin divers out of plastecene as well as making models. He currently spends approximately 10-15 hours per week drawing, though he would like to do more if his schedule permitted.

NH currently draws with a unique style that generally invokes bright colours and geometric patterns and may include other objects pasted in. He generally prefers to keep all of his original artwork, but he has donated images or replicas of his artwork to various charities.

The two art judges mentioned in the context of MG's case study, also commented on NH's work. They found some of his work particularly striking. Taking it a step further, they indicated that some of his artwork was on par with work they see in exhibitions of contemporary art.

For an example of NH's artwork, consult Figure 8-6.

Figure 8–6. Example of NH's Artwork.

8.7.3 Results and Interpretation:

Clinical Measures:

WAIS-III (see Figure 8-7)	
FSIQ:	123
VIQ:	122
VC: (Vocab + Sim + Info)	120
PIQ:	121
PO: (PC + BD + Matrix)	138

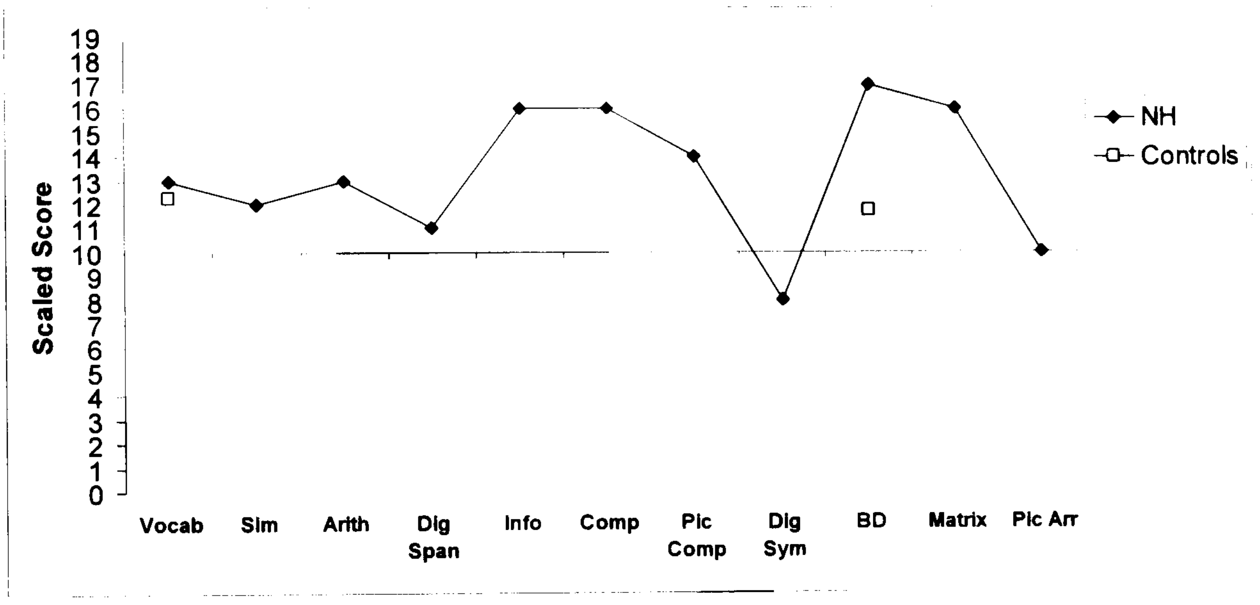


Figure 8–7. Profile of NH's IQ Scores.

Experimental Measures:

Table 8-5 presents IQ and experimental task results for NH as well as those of his comparison group.

Table 8–5. Performance on Tasks Administered to NH and Matched Controls: Mean (SD).

Test	NH	TD Control Group (n=7)	t	*p*
Age	43.83	40.68 (7.45)	0.40	.71
FSIQ	123	111.57 (11.80)	0.91	.40
Vocabulary	13	12.29 (3.40)	0.19	.85
Block Design	17	11.71 (1.60)	3.09	.02
EFT				
% Corr All	100	86 (10)	1.31	.24
Avg Time All	5.20	19.59 (7.40)	1.82	.12
% Corr Adult Items	100	77 (17)	1.27	.25
Avg Time Adult Items	6.50	27.44 (10.40)	1.88	.11
Implicit Learning				
Prop RT Gain between 1st & 2nd Halves	.18	.06 (.18)	0.62	.56
Sentence Completion				
No. of Loc Comp	0	0.29 (0.49)	0.55	.60
Im/Possible Figure Categorisation				
No. Corr Poss Fig	10	9.00 (0.63)	1.47	.20
Avg RT to Corr Poss Fig	2919	2020.68 (994.59)	0.84	.44
No. Corr Imp Fig	10	8.50 (1.97)	0.70	.51
Avg RT to Corr Imp Fig	3810	2077.88 (657.82)	2.44	.06
IT	39	33.43 (8.54)	0.61	.56
Folk Physics % Correct	65	63.57 (18.19)	0.07	.94
EQ	17	42.14 (15.49)	1.52	.18
SQ	32	24.86 (9.96)	0.67	.53
AQ Total	42	13.57 (4.65)	5.72	.001
AQ Social Skills	9	2.29 (2.69)	2.33	.06
AQ Attention Switching	10	3.43 (1.81)	3.39	.01
AQ Attention to Detail	6	4.57 (1.13)	1.18	.28
AQ Communication	9	0.86 (1.07)	7.12	.0004
AQ Imagination	8	2.43 (1.81)	2.88	.03

Adult Sensory Profile				
Sensory Sensitivity	53	29.17 (8.80)^	2.51	.05
Sensation Avoiding	58	31.33 (6.25)^	3.95	.01
Low Registration	46	30.67 (6.15)^	2.31	.07
Sensation Seeking	32	45.50 (8.34)^	1.50	.19
Navon-type Stimuli % Local Matches	100	NO DATA		

^ n=6

Given that the two art judges considered some of NH's work on par with that of contemporary artists currently exhibiting in the community, his savant-level skill was confirmed and would be considered at least talented.

Overall, results from NH's self-report, using the AQ, are consistent with his diagnosis. In spite of his relatively high verbal IQ, these results indicated particular difficulty for NH in the communication domain. NH presents with an IQ profile that is above average generally (i.e., FSIQ, VIQ, and PIQ). Not surprisingly, given NH's diagnosis, Block Design was the most elevated subtest score. Interestingly, Digit Symbol Coding was the lowest subtest score, likely reflecting NH's methodical processing style apparent not only in his output during testing (e.g., RT to correct identification of impossible figures), but also during social interactions and completion of his artwork. Indeed, he was noted to take a very long time to finish any one piece of artwork, which is not surprising given the level of detail of his artwork and the precision which is needed in order to produce such geometrically intricate designs.

NH stated to me: "I like patterns and detail. I don't have an overall plan for a picture, but draw piecemeal, one small area at a time, which hopefully will form a coherent whole." This self-description of his drawing style certainly brings to mind WCC. Results from experimental tasks supported this contention. NH exhibited a completely part-oriented approach when asked to match Navon-type letter stimuli at either the local or global level, whichever he preferred. Indeed, when asked to match letters at the global or local levels, 100% of the time, he responded locally. Combining data from the present thesis with that in Booth's thesis (2006), this task was administered to approximately 300 TD children and adults (ages 7-25 years) and NH is one of only six people to have answered in a 100% local fashion on this task. Additional evidence of WCC was observed in NH's Block Design score, which was significantly higher than that of the matched control group. Moreover, NH showed both perfect accuracy and very fast solution times when asked to find hidden figures on the EFT, though the differences between his scores and those of the comparison group just missed reaching statistical significance. Additionally, NH demonstrated perfect accuracy in identifying im/possible figures, though his speed in identifying impossible figures, in particular, was significantly slower than the mean score obtained by the matched control group, another possible indication of his methodical processing. Finally, as for case MG, NH did not provide any local completions when asked to finish off a series of incomplete sentences; however, as argued earlier, this finding likely reflects the poor sensitivity of this instrument for adult populations, rather than lack of WCC.

NH was also given a test of Folk Physics to assess his natural ability to work with everyday "systems". His score was in line with those for the age, gender, and IQ matched control group and therefore within expected parameters. NH scores on the systemising quotient were comparable to those obtained in the male control group, but his empathising quotient was considerably lower (though not significantly so) than that of the matched control group. Just as observed for case MG, performance on these two questionnaires was notable because an opposite pattern of scores was observed for the case as compared to the controls; NH (like MG) scored higher on the SQ than the EQ, the reverse of what is found for the matched control group.

NH's implicit learning and IT scores were also commensurate with those of the matched control group (consistent with results obtained with cases MG and NC and the group results reported in Chapter 6), further suggesting that a "gateway" model may best explain the role of these cognitive functions in savant skill development.

Compared to matched controls' self-ratings using the Adult Sensory Profile, NH, like MG, exhibited significantly greater sensory sensitivity and avoidance, along with lower sensory registration. However, in spite of this, NH's tendency to seek out sensory experiences was not detrimentally affected as compared to matched controls. Just as with case MG, NH's categorical ratings for each of the four indices were extreme, so that his score was considered 'very high' for sensory sensitivity, sensation avoiding, and low registration, while his score for sensation seeking was considered 'very low'. This contrasted with ratings from the control group, for whom extreme scores were rare. Only one participant received a rating of 'very low' on the sensation seeking index; otherwise, no 'very high' or 'very low' ratings were noted.

8.8 Comparison of Performance Across Cases

Trends in performance on experimental tasks across the diverse savants discussed above were examined. Scores by savants that were higher (or lower) than one standard deviation from the mean of the matched control group were considered strengths (or weaknesses). Table 8-6 presents a comparison of savant performance on each prototypical task of the four domains (WCC is represented by two tasks, the EFT for good featural processing and the sentence completion task for poor global processing) proposed as important to savant skill development. From this cross-case comparison, the data support a gateway model for implicit learning and processing speed (at least the data are not inconsistent with this notion), since performance on the relevant tasks consistently remained within one standard deviation of performance by (non-ASD) matched controls. There was some indication of superior segmentation ability by savants, particularly the artists, which is consistent with performance by other savant (Cox & Eames, 1999; Pring et al., 1995) and nonsavant (Pring et al., 1995) artists and indicates its importance in art skill development. Poor use of context to process verbal information was demonstrated by the two child savants while performance for the two adult savants was uninterpretable since the Sentence Completion task does not appear to be sensitive for adults with high VIQ (whether TD or ASD). Performance on the time reproduction task was very good for the lone calendar savant and commensurate with the matched control group for the savant artist who also showed excellent visuospatial recognition memory. Excellent memory test performance by both VT and MG may be reflected in faithful time window reproductions as well.

Table 8–6. Domain Specific Performance by Savants Relative to Matched Controls.

Savant	EFT	Sent Comp	Implicit Learning	Time Rep	IT
VT	+	-	=	=	
NC	=	-	=		=
MG	=	=	=	+	=
NH	+	=	=		=

+ savant performance superior to controls' by at least one standard deviation

= savant performance within one standard deviation of controls' performance

- savant performance at least one standard deviation worse than controls'

8.9 General Discussion

Applying Treffert's (1989) criteria to this sample, each of the four savants described in this thesis would be considered at least "talented" (if not "prodigious") based on their performance and/or subjective evaluation. Furthermore, MG's calendar calculation ability, the most clearly quantifiable skill, was shown to be exceptional (and therefore "prodigious"), even by calendar savant standards, given his accuracy and speed for answering calendar questions over a very wide range of years. Labelling one or more of the art savants as prodigious is difficult, but based on the impressions of the two experienced art judges and previous commentary, each of these artists display technique and creativity at least comparable to other same-age professional artists, providing confidence in their presumed high skill level. The mechanical savant was also deemed exceptional based on the evaluation by an experienced engineer, who thought his skills were very impressive, given his age level.

For MG's calendar calculation ability, it is clear that both good mental arithmetic and some knowledge of calendar structure, whether explicit or implicit (certainly possible, given that other savants, like MG, who has relatively good expressive language abilities, experience difficulty in attempting to describe how they do it), contributed to outstanding skill in this domain. Case MG showed amazing calendar range, but he also showed fast and accurate mental calculation skills that mirror results from Cowan and colleagues (2003), who found evidence of good to exceptional mental calculation abilities amongst a majority of the 10 calendar savants they tested. MG also demonstrated a proclivity toward good memory for number-related material (i.e., Census data), which is similar to results obtained from the calendar savants described by Heavey et al. (1999).

Mechanical aptitude seemed to be most related to two key elements: an intuitive understanding of the way things work and an "obsessive" interest in how things work. NC's good score on a test of folk physics (comparable to that of the TD adult control group) only served to reinforce and validate the suspicion of his good understanding of mechanical systems. Providing further substantiation, Baron-Cohen and colleagues (2001) also found better understanding of folk physics amongst children with ASD than amongst TD kids. In NC's case, perhaps even more than the other three savant cases reported here, a single-minded pursuit of his interest in the relevant savant domain was a strong driving force behind skill development and maintenance. Findings from this case study echo reports provided by Hoffman and Reeves (1979) and by Brink (1980) in indicating a crucial role for motivation in the development, maintenance, and expansion of mechanical skills. It has been clearly shown that mechanical interests are highly endorsed amongst many "restricted" interest areas commonly associated with ASD (Baron-Cohen & Wheelwright, 1999). The importance and role of motivation, although difficult to quantify, cannot be overstated in expression of savant-like skills, whether in the context of ASD and other neurodevelopmental disorders or amongst TD individuals. In the case of ASD, the lines between what is termed "motivation" and what is called a "restricted interest" are often blurred. Nevertheless, this strong drive to pursue one's interest(s) only serves to maintain and possibly expand skill development. Indeed, motivation, in the form of intense practice, has been implicated in skill development in a variety of talent domains for savants, prodigies, and other talented individuals. In fact, Ericsson and Charness (1994) as well as Howe, Davidson, and Sloboda (1998) have taken this view to its most extreme by accounting for prodigal and savant performance purely through these individuals' strong interest and intense practice. However, the notion that exceptional performance in most domains can be replicated through extensive practice has been met with much resistance. Based on the findings presented here, a combination of strong interest in and aptitude (even early on) for understanding mechanical systems, most clearly describes the ontology of mechanical skills demonstrated by NC.

While on the topic of environmental factors contributing to savant skill development, it should be noted that during the completion of MG's case study interesting non-empirical evidence emerged that has particular relevance to the often obscure and mysterious skill of calendar calculation. Cultural and societal factors may help to explain why calendar calculation skills are unique to individuals with ASD versus TD individuals. Although individuals with calendar skills may be encouraged and reinforced for their success in calendar calculation (compared to their other daily living and academic endeavours), an argument could be made that individuals with ASD, because of difficulties in theory of mind and social understanding, are not as susceptible to conform to the broader culture's norms. Hence, a seemingly idiosyncratic skill like calendar calculation can develop and thrive in this context, while it would face more "obstacles" in the context of typical development. Indeed, MG has succeeded where few others, even those with ASD, have; he has incorporated his interest in and knowledge of calendar and date information into his artwork.

Artistic ability amongst three of the four savants was associated with not only good perceptual organisational abilities but also good visuospatial recognition memory. Studies of TD chess experts reveal much better (and superior to controls) chess-related memory than general memory (Green & Gilhooly, 1992). In this vein, differences in cortical integration (as measured by EEG coherence and synchrony) between artists and non-artists show that artists may have a stronger representation of art-related material than do non-artists (Bhattacharya & Petsche, 2005). Visuospatial stimuli, such as visual artwork or pictures, may then have stronger representations amongst artists than non-artists. This stronger representation may be the reason that one savant, VT, demonstrated superior visuospatial recognition memory, which was far out of line with his general cognitive abilities. As mentioned previously, it is unusual amongst savants to document superior scores on standardised assessment tools, but several studies of savants have shown excellent domain-specific memory in contrast to both general memory and intellectual abilities. For example, one savant's memory for musical pieces was outstanding, compared not only to his overall cognitive functioning, but also to that of a TD pianist (Sloboda et al., 1985). Also, amongst individuals with ASD who memorise bus schedules, O'Connor and Hermelin (1989) found enhanced domain-specific memory for numbers recognisable as "home" or familiar routes versus memory performance in line with their IQ for those numbers that were not familiar. However, findings of an art savant's visuospatial recognition memory as particularly good and discrepant from general cognitive abilities stand in contrast to three studies showing that visuospatial recognition memory in art savants is associated with cognitive rather than graphic ability (O'Connor & Hermelin, 1987a, 1987b, 1990). It is difficult to determine how this may relate to VT's artistic ability. Although tempting to invoke eidetic memory and similarities to previously reported cases of savants who draw/paint from memory alone (e.g., Hermelin et al., 1999) resulting in almost perfect, "photographic" reproductions, VT does not complete his drawings in this manner. VT may be capable of drawing eidetically, but he tends to draw from his imagination, usually involving specific and repeating themes and characters.

Along similar lines, examination of the clinical data presented for case MG shows that he was perseverative on the WCST, yet showed good flexible knowledge of the calendar when asked questions from different angles. For example, he was asked standard calendar questions such as: "What day of the week was 30 September 1980?", but he was also asked questions to assess this knowledge from a different perspective, such as "In what years does 15 January fall on a Monday?" This juxtaposition of good flexibility in one domain and poor flexibility in another seemingly parallels Heavey et al.'s (1999) demonstration of unexceptional scores on conventional memory tests by calendar savants, yet when these savants were presented with a list of "items" in a format roughly akin to a date from a calendar, they outperformed controls. Since executive functions (including cognitive flexibility as assessed by the WCST) and memory are conceptualised as central, domain general cognitive functions, savants, like case MG, provide evidence for interesting dissociations based on the domain in which these functions are exercised. Indeed, VT's superior visual recognition memory may also apply here, given how out of line his memory performance was from his IQ score.

A direct comparison of savant performance across the various experimental tasks (in the four key cognitive domains) was made. WCC was documented on some level for each of the savants (even MG, though not shown on tasks presented in Table 8-6). Moreover, intact implicit learning was documented in all four savants. Processing speed was found to be intact as well for the three savants to whom the IT task was administered. Finally, time reproduction was found to be good for one savant and average for another. These results are consistent with a model in which WCC is a required building block for savant skill development and in which other key cognitive functions (i.e., implicit learning and mental processing speed) need to be intact (at least) in order for one to exhibit talented or prodigious savant skill levels.

8.10 Summary

A case studies approach was utilised to examine individual cognitive profiles amongst four highly gifted savants. WCC was exhibited to some degree on at least one task by each of the four savants. Implicit learning was found to be intact amongst all the savants. Time perception performance was found to be variable, depending on the task, but generally findings revealed intact or better time reproduction. And finally, for the two adult savant case studies, sensory-perceptual functioning was found to be abnormal. What follows is a final discussion considering findings from both the group study and the savant case studies.

Chapter 9: Final Discussion and Conclusions

The following chapter aims to summarise briefly the findings from this thesis, draw out the theoretical conclusions, consider the limitations of the studies, and propose future directions of inquiry.

The central goal of these studies was to investigate possible cognitive mechanisms that contribute to, allow for, and/or underlie savant skill development in ASD. The model proposed in this thesis holds that 1) WCC is necessary but insufficient for savant skill development in ASD, 2) implicit learning is superior in savant and nonsavant individuals with ASD as compared to matched TD and MLD controls, 3) IT represents untapped potential in ASD that may be manifest as savant skills in select cases, and 4) sensory-perceptual idiosyncrasies may contribute to savant skill development, particularly in certain domains. Based on the group studies discussed in Chapters 6 and 7 and the series of case studies reviewed in Chapter 8, part 1 of the model was clearly supported, while points 2-4 received only mixed support.

9.1 Summary of Main Findings

All four savants discussed in Chapter 8 exhibited WCC on at least one task. Moreover, there was some indication that savant artists were particularly good featural processors, consistent with previous findings (Cox & Eames, 1999; Pring et al., 1995). Nevertheless, savants demonstrated levels of WCC comparable to that of nonsavant individuals with ASD. These findings are consistent with a model positing that WCC is a required building block for savant skill development and would help to explain the overrepresentation of individuals with ASD amongst those possessing savant skills.

As predicted, WCC was evident for individuals with ASD (whether savant or nonsavant), as compared to their matched controls. In particular, both nonsavant individuals with ASD and the savants with ASD showed superiority in disembedding performance, consistent with previous studies (Jolliffe & Baron-Cohen, 1997; Ropar & Mitchell, 2001; Shah & Frith, 1983). Moreover, both the savant and nonsavant children and adolescents with ASD demonstrated difficulties in using context to process verbal information (Jolliffe & Baron-Cohen, 1999, 2000; Snowling & Frith, 1986), unlike their matched non-ASD controls. Finally, nonsavant children with ASD, when presented with a Navon-type task, tended to match stimuli more locally than did controls and one savant who completed this same task matched locally on all trials presented to him. WCC may therefore represent a building block skill, possibly necessary, but certainly insufficient for savant skill development. Such a possibility has been eloquently delineated by Heaton and colleagues (1999) within the domain of music and by Heavey and colleagues (1999) within the domain of calendar calculation. To summarise, they both propose that a detail-oriented cognitive style leads to the development of good building block skills in savant domains, such as good pitch processing in music and good day-date associations in learning calendar information. The WCC data from this thesis further support this line of reasoning.

As a proxy for understanding how savants learn within their area of talent, a visuospatial implicit learning task was used to assess implicit learning abilities. Implicit learning was found to be intact in ASD, with comparable performance to that observed amongst matched controls, which replicates findings from one previous study (Klinger et al., 2001), while contradicting findings from another (Mostofsky et al., 2000). The differing nature of the tasks utilised in these studies, with Klinger et al.'s (2001) more closely resembling the task designed for the present thesis, may be responsible for the discrepant results. Though implicit learning was generally good amongst the savants, like the nonsavant individuals with ASD, it was certainly not superior to learning effects observed in the comparison groups. Intact, but non-superior performance indicates that good implicit learning, as found for all four savants, may be required for savant skill development, though again, it alone would be insufficient.

Mental processing speed, similar to implicit learning, was comparable between those with ASD (with or without savant skills) and their comparison groups. Even though this did not support the hypothesis of superior information processing speed amongst savants, there was some indication that the cognitive architecture of those with ASD is differently organised to those without ASD. The robust relationship between IQ (particularly nonverbal IQ in this case) and IT was replicated here for the groups of TD children and the group composed of both TD and MLD children. However, this strong correlation was not found in the ASD group, perhaps reflecting good intellectual potential in ASD that is not expressed in typical IQ tests because of the social demands of the task and the reliance of these tests on culturally transmitted knowledge and skills. Nevertheless, intact processing speed may be a necessary element for the development of savant skills. Perhaps IT does in fact measure "potential" in ASD; instead of being expressed in IQ scores, it may be demonstrated in savant or savant-like skills.

In this thesis, perceptual functioning beyond that revealed using WCC tasks was assessed primarily via tests of time perception, a domain that has received very little attention in the autism literature. Perfect appreciation for time passage has been reported in a few individuals with ASD (e.g., Treffert & Wallace, 2002); nevertheless, only one study to date has examined functioning within this domain amongst those with ASD. Szelag et al. (2004) showed a deficit for people with autism in the reproduction of small durations no longer than two or three seconds. In spite of this finding, individuals with ASD were expected to reproduce the larger time intervals used in the present thesis more faithfully than matched controls. In line with predictions, individuals with ASD exhibited not only relatively good time reproduction (as compared to time estimation and time production) when looking within this participant group, but also indications that performance was superior to that found in the matched control group. Given anecdotal reports of faithful, unaltered memory traces for individuals with ASD, this is perhaps unsurprising, but previous attempts at assessing savant-like memory skills in ASD have proven elusive. Although none of the four savants reported a perfect appreciation for time passage, the two savants tested using the same time perception battery demonstrated time reproduction performance (even when other aspects of time perception may have been worse) comparable to that of the matched controls, with one savant showing trends for better than comparison group performance. Perhaps a time reproduction paradigm such as the one used here more readily reflects the "tape recorder" analogy used to describe good rote memory in ASD and thought to be reflected in such behaviour as echolalia of speech. Traditional tests of memory often confound semantic and perceptual elements in stimuli by using words and pictures of usually nameable and meaningful things or actions. Time reproduction avoids these trappings, though good basic sustained attention is certainly required to complete the task.

Amongst TD children, correlational analyses revealed age-related changes in performance on the EFT and in the identification of im/possible figures, consistent with previous findings (Witkin et al., 1967; Young & Deregowski, 1981). Performance on several tasks in the group of TD and matched control children was correlated with IQ scores, particularly Block Design scores (i.e., EFT, im/possible figures, and IT). These relationships to nonverbal ability likely mediated correlations between various experimental tasks in the TD and matched control groups (i.e., between performance on the EFT and on im/possible figure identification, RT gain in the segmented Block Design condition, and IT). Indicating some unity of construct, all three time perception tasks were generally correlated with one another amongst the TD and matched control children. For those with ASD, only the time estimation and time production tasks were correlated with one another, isolating the time reproduction task. It could be that children with ASD were using a unique cognitive strategy (or strategies), such as strong reliance on good rote memory.

To complement and extend correlational analyses, subgroup analyses were conducted based on performance on several prototypical tasks from each of the key cognitive domains assessed in this thesis. WCC, as indicated by good local processing on one task (i.e., EFT) and poor global/contextual processing on another task (i.e., sentence completion task), was more prevalent in the group of children with ASD than in the TD children. Interestingly, shared WCC and good implicit learning performance was also more prevalent amongst the group of ASD children than amongst the group of TD children. This subgroup may indicate a differently organised implicit cognitive system in ASD that may predispose these individuals to successfully, but unconsciously learn basic rules and regularities in highly organised systems reminiscent of savant domains (e.g., calendars and music).

In addition to the results obtained from the experimental tasks utilised in both the group and case studies, there were other converging data worth noting amongst the case studies. Within the domain of art, all three savant artists shared good visuospatial processing skills, which were out of line (i.e., superior by at least one standard deviation) with their overall IQ. O'Connor (1989) showed that amongst nine savants with discrepantly high nonverbal IQ (10+ points > VIQ), five were artists. Though there were savant artists in the other two IQ groupings (i.e., approximately equivalent IQs and discrepantly high VIQ), this general association may hold. Answering whether or not these abilities were pre-existing or were amplified by practice with and exposure to visuospatial material was not possible in the context of this thesis. These relatively good nonverbal IQ scores likely reflected both a pre-existing strength and a natural inclination toward further development in this area because of this relative strength. In this sense, the association was valid regardless of its developmental ontogeny.

As an additional assessment of sensory-perceptual functioning, a questionnaire of sensory experiences and preferences was administered to the two adult savants and their adult control group. Findings indicated that the savants presented with profiles of idiosyncratic sensory experiences, but common to both savants and significantly different from the control group were greater sensory sensitivity and a general avoidance of certain sensations considered aversive. Whether and how these sensory issues may contribute to savant skill development is difficult to determine and may be a function of their ASD alone (Rogers & Ozonoff, 2005) and unrelated to the savant skills. Nevertheless, this area requires further investigation to understand better the potential links between sensory-perceptual idiosyncracies and savant skills in ASD. For example, individuals with Williams syndrome, another group purported to exhibit surprisingly good musical skills (Levitin et al., 2004), were reported by parents to demonstrate many auditory anomalies, significantly more than those reported by parents of individuals with autism, Down syndrome, or TD controls (Levitin et al., 2005).

Overall, these group study results both introduce novel findings and provide confirmatory evidence to the field of autism research. WCC was shown to be prevalent (though neither unique nor universal) in ASD; however, corroborating the extant literature, poor global processing was inconsistently noted while good featural processing was robust. In one of only a few examinations of implicit learning in ASD, performance on a hybrid serial reaction time-statistical learning task was found to be as good as that of matched controls. In only the second recent study to examine time perception in ASD, time estimation and time production were found to be intact while there was some indication that time reproduction may be better than that found for matched controls. In follow-up to previous studies indicating good processing speed despite low IQ in ASD, IT in ASD was found to be comparable to that documented for matched controls, while the correlation between IT and IQ was significant for the matched controls but not so for the children with ASD. Finally, individual differences were examined via subgroup analyses. Building on the previous group findings, consistent WCC across two prototypical tasks was significantly more common in the group of ASD children than in the group of TD children. Moreover, performance indicating both good implicit learning and WCC was more likely found in the ASD group than in the group of TD children. This confluence of good performance may result in cognitive assets, such as savant skills, in ASD.

9.2 Theoretical Relevance

Findings from the present thesis have implications for several theories reviewed in Chapter 2 particularly. In Mottron et al.'s (2006) recent update of the EPF model in ASD, they delineated eight principles of perception in ASD, which were numbered in order of what the authors' considered most agreed upon to most speculative. Unsurprisingly, at least two of these principles have direct relevance to the findings presented in this thesis. The first principle, "the default setting of autistic perception is more locally oriented than that of non-autistics", requires no additional elaboration (since it has been discussed already under "Summary of Findings" in this chapter and in Chapter 7) and was clearly supported here, as it has been previously in numerous studies. The sixth principle states that "perceptual expertise underlies the savant syndrome". This principle contains a number of features relevant to the present thesis. Mottron and colleagues state that "savant abilities always involve a behavioural pattern of a single restricted and repetitive interest for a certain class of stimuli, such as pitches, words, or letters". They surmise that this leads to a "stoppage rule" restricting savant capabilities to only one or, exceptionally, two or three skill domains. Given that Mottron and colleagues consider memory alone a savant skill, it could be argued that MG, as described in this thesis, demonstrates four savant skills (i.e., art, calendar calculation, mental calculation, and memory), which precludes only one restricted interest feeding into any one of these skills. Indeed, MG may be considered an exceptional case because of his multiple talents, but there are also a number of examples described in the research literature (Pring, Hermelin, Buhler, & Walker, 1997) and anecdotally reported, which indicate that savant skills may not stand alone or be driven only by a single-minded pursuit of one interest. As part of this sixth principle, implicit learning is invoked as representative of savant learning, similar to the proposal proffered here. Findings from this thesis provide tentative support for this contention, only in so far as implicit learning appears to be intact in ASD and in four savants; thus, ruling out impairment in this domain.

According to Baron-Cohen's (2006) systemising theory of ASD, also briefly mentioned in Chapter 2, people with ASD are keyed into closed systems with minimal variance, such as the fairly lawful nature of savant domains, and are unable to process and distressed by open systems with maximal variance, such as social behaviour. Three of the savants described here were administered tasks assessing systemising and were found to be hypersystemisers compared to TD controls, though their systemising levels were no higher than scores one would expect from other individuals with ASD. The systemising theory also predicts that people with ASD will be good at detecting patterns, particularly in more lawful systems. Given findings of intact implicit learning, this contention may be supported. However, from the present author's reading, it seems unspecified as to whether this facility for pattern detection, as laid out in the systemising theory, is an explicit or implicit process (or both). Nevertheless, it may be that this detection comes to explicit awareness at some point, as reflected by difficulty with prediction in highly variable systems leading to perseveration and difficulty with change. It may be particularly fruitful to integrate these findings of intact implicit learning in ASD (both from this thesis and other studies, e.g., Klinger et al., 2001) with the appealing notion of systemising in ASD, especially if future work can dissociate implicit learning performance for this group based on the "system" or domain in which implicit learning can be demonstrated. Different tests of the ability to master a novel system could be developed to identify what characteristics of data organisation help or hinder individuals with ASD.

Findings from this thesis also have significant ramifications for at least one theory of general intelligence and how the paradoxical nature of the savant may or may not inform this theory. As reviewed in Chapter 4, Anderson (2001) has described a theory of the minimal cognitive architecture underlying intelligence and cognitive development. This theory indicates that knowledge, as reflected in traditional IQ measures, is acquired via two main routes: thinking and modular systems. One significant constraint on thought is the speed of a basic processing mechanism (measured by IT), which in turn determines individual differences in general intelligence. The focus in the present thesis fell particularly on the relationship between processing speed and intelligence in the context of ASD and on examining processing speed in a series of savants with various skills. Testing savants of average range and higher IQs extended previous work (Anderson et al., 1998) and the results of this testing corroborated findings of intact IT in savants, though they did not fit with the present author's predictions of superior IT in savants. In Anderson's model of minimal cognitive architecture, modules can be heritable, with likely examples including those mediating face processing and language processing. However, modules can also be acquired, which may include and describe several savant domains, given the likely feedback loop involving inherent interest and/or skill in a particular domain and the associated pursuit of this interest, whether through practice or simple exposure. While in Anderson's model there is no link between IT and modular processing, in the case of savants, it would be interesting to postulate that IT is more representative of modular processing (in savant-related domains) than for TD individuals and individuals with MLD. However, it was clear that for several savants, IQ and IT were both intact. Moreover, the top-down processing of average or better intellectual levels likely exerted additional influences on not only the savant skill domain, but the output of this skill (i.e., artwork in this case). So, for example, MG, unlike most savant artists, demonstrated a variety of artistic styles in his work and a keen interest in sampling a variety of styles and media of expression. Moreover, he not only incorporated his own idiosyncratic interests (e.g., in dates and calendars) into his artwork, but he also was interested in other artists' work, which is fairly unusual amongst savant artists.

In this thesis a "gateway model" has been proposed to conceptualise the relationship between these core cognitive domains and the development of savant skills. Frith and Happé (1998) proposed a gatekeeper-type model for both autism and dyslexia, wherein a primary cognitive deficit leads to other downstream deficits. So, in the case of autism, Frith and Happé propose that a deficit in theory of mind can result in other downstream deficits (e.g., language acquisition), because of their shared reliance on understanding of intentions, for example. The "gateway model" proposed here relies on similar logic. Instead of an underlying cognitive deficit contributing to other downstream difficulties, an intact or enhanced cognitive function is proposed to be necessary and allow for skill development. The model holds that these core cognitive elements serve as a prerequisite to the development of savant-like skill. Since these core cognitive domains are intact or superior in ASD, combined with the propensity of these individuals to develop restricted interests, the "stage is set" for the surprising development of savant or savant-like skills. The present thesis targeted only a few of a number of likely influences on savant skill development and maintenance; however, these cognitive mechanisms are conceptualised to contribute to all skill levels and may indeed serve as a gatekeeper to the emergence of some, if not most, types of savant skills.

One could conceptualise an additive and/or interactive model for these core cognitive domains. Though implicit learning performance did not differ between individuals with ASD and comparison groups, featural processing was indeed favoured amongst the individuals with ASD. To this end, enhanced low-level discrimination and featural processing may lead to the development of a differently organised implicit cognitive system than would otherwise be the case. For individuals with ASD this system may be especially sensitive to domains containing high internal structure, such as music and calendars, and a prevalence of simple (usually perceptual rather than conceptual) information. This provides one speculative way that these cognitive mechanisms may not only act to enable an individual with ASD to develop savant-like skill, but also interact with one another to this end.

Extending this work to the exploration of basic biological mechanisms may also prove fruitful. There is some evidence that savant skills have genetic relevance, whether based on linkage studies (Nurmi et al., 2003) or studies involving genetically informative populations (Dykens, 2002; Levitin, 2005), though more precision in measurement is desirable and may help to clarify this relationship and the sometimes conflicting findings (e.g., Ma et al., 2005). Further genetic studies could help to better inform how the notion of talent and savant skills may be related. As previously mentioned, it seems that individuals with similar skills to savants (e.g., artists and musicians with AP), also display some of the unique cognitive characteristics of these individuals, such as good segementation abilities (Brown et al., 2003; Pring et al., 1995). Moreover, inheritance patterns of savant and savant-like skills need to be assessed via family studies. For example, family (Baharloo, Service, Risch, Gitschier, & Freimer, 2000) and twin studies (Drayna, Manichaikul, de Lange, Snieder, & Spector, 2001) suggest that AP, a skill overrepresented amongst individuals with ASD and seemingly universal amongst savant musicians (Miller, 1989), is highly familial and heritable. To this end, preliminary work from Young (1995) indicates that relatives of savants may be more likely to exhibit savant-like skills than do relatives of nonsavant individuals. Of course, environmental factors (e.g., socioeconomic factors and exposure to material within savant domains via education and training) need to be accounted for and may also prove informative, as they have in models of gene-environment interplay in the expression of skills such as AP (Zatorre, 2003). Taking it a step further, it may be that relatives of individuals with ASD (with or without savant skills) exhibit more skills within savant domains partly because of their propensity to demonstrate subclinical ASD traits (e.g., good segmentation abilities: de Jonge, Kemner, & van Engeland, 2006; Happé et al., 2001) that are associated with savant domain skills amongst non-ASD gifted individuals (e.g., Brown et al., 2003; Pring et al., 1995). We have only begun to scratch the surface of potential genotype-phenotype relations in ASD. As more studies demonstrate the robustness of certain phenotypic traits in ASD and technological advances allow for more fine-grain and affordable genotyping, this approach should gain momentum.

All the same, phenotypic clarity is continuously sought, especially within a complex disorder, such as ASD, that results in variable clinical presentation. The relationship between savant skills and the rest of the non-social aspects of the triad of impairment also needs to be elucidated. Occasionally, assumptions are made that savant skills are nothing more than an expression of restricted interests in ASD, consistent with the motivational and practice-based models for understanding skill acquisition; nevertheless, it remains to be shown how savant skills may relate to other aspects of this third piece of the triad of impairment. Factor analytic studies of large populations, which may now be possible with the large international collaborations underway (e.g., the International Molecular Genetics Study of Autism Consortium), may help to clarify the picture. Though related to one another phenotypically, intense interests/repetitive nehaviors and savant skills may dissociate in correlations with genotype, which may also provide indication of aetiological independence.

In the pursuit of biologically relevant mechanisms, functional and structural neuroimaging (e.g., MRI, DTI, fMRI, MEG, etc.) studies also may prove to be particularly informative in the study of savant skills. Having savants complete tasks while in the scanner will help to isolate regions uniquely activated for this group (e.g., Boddaert et al., 2005). Moving beyond localisation models will also prove revealing. For example, utilising functional techniques to demonstrate change(s) in activation strength by modulating task difficulty or by subgrouping members based on phenotypic traits may move forward brain-based models. Of course, it will be important to utilise the best control groups available. So, for example, one could utilise age, gender, and IQ matched controls, but it will also be informative to include a control group matched for skill (e.g., AP). This similarly skilled control group will help to control for both exposure and practice.

Savant skills are often presented as amazing and exceptional, almost to sensational levels. Hence, they have often been described in a light that has seemingly little scientific relevance. In contrast, what is becoming clear from the burgeoning literature, is the potential relevance of savant skills not only to better understanding talent and skill development in general, but also to elucidating models of intelligence, learning, and memory, and aetiological mechanisms on various levels (i.e., biological and behavioural).

9.3 Limitations and Future Directions

The present thesis has provided insights into possible cognitive mechanisms underlying the propensity of individuals with ASD to exhibit savant or savant-like skills. The weight of the evidence suggests that WCC, implicit learning, and processing speed may be key cognitive mechanisms that facilitate this skill expression in ASD. However, despite moving forward the literature by providing these insights, a number of limitations were noted. In general, WCC received mixed support in this thesis in characterising the cognitive style of individuals with ASD; however, good featural processing seems to be a consistent finding both in this thesis and in the extant literature, with most of the controversy involving global processing deficits in ASD (Happé & Frith, 2006). The plethora of studies reviewed in this thesis highlight the diversity of methodologies and corresponding task demands inherent to the documentation of this unique feature of cognition in ASD. Indeed, tasks requiring contextual and hierarchical processing are interspersed amongst the studies grouped under the rubric of central coherence. Unfortunately, the collapsing together of various processes creates difficulty when moving beyond the descriptive level, particularly in attempts to examine the underlying cause of this idiosyncratic cognitive style. For example, if speculating as to the neural basis of this cognitive bias, attempts are rife with difficulty. Many neuropsychological/lesion (both developmental and adult) and neuroimaging studies have been conducted in the areas of contextual and hierarchical processing; however, crossing perceptual modes (verbal, musical, visuospatial, etc.) and levels of processing (from low-level perception to higher-level reasoning abilities) only muddies attempts to form a coherent picture of the neural deficit involved. Given that evidence from this thesis and elsewhere demonstrates a relationship between WCC and savant skills, determining the neural basis for this cognitive style may be particularly informative to understanding better not only ASD, but also the presence and overrepresentation of savant skills in ASD. Because savant-like skills have proven to increase genetic linkage (Nurmi et al., 2003) and non-social features of the ASD phenotype have demonstrated high heritability (Ronald, Happé, & Plomin, 2005), bridging the gap from cognition to gene via brain-based findings may be particularly effective in developing a causal model for ASD (Frith, 2001).

One aim of this thesis was to examine possible underpinnings of savant skills amongst individuals with ASD. One question that arises from this inquiry is: what distinguishes those nonsavant individuals with ASD from those individuals with both ASD and savant skills? In general, no single factor characterised the cognitive profile of all savant case studies presented here. However, within individual case studies, idiosyncratic and surprising findings were noted (e.g., excellent memory by case VT, sensory difficulties for both adult savants). It remains possible that weaker central coherence and discrepantly fast IT were present amongst the savant (as opposed to nonsavant) individuals with ASD, but that the insensitivity of the measures utilised here prevented detection of these differences. Moreover, though savants are rare, a larger group of these individuals is needed to determine whether all savants demonstrate WCC and is better suited to determine if there is a dissociation between cognitive characteristics, like WCC, and savant skills.

Implicit learning has been invoked frequently to explain sudden savant skill development, but rarely has this hypothesis been tested. As a first attempt at answering this empirical question, a novel, but basic implicit learning task was developed. Because the implicit learning task used in this thesis was quite general and simple (utilising coloured shapes that could be identified easily by children with MLD), future research should further probe this particular cognitive function in more complex ways. It would be particularly important to contrast "learning" due to repeated exposure to material within a specific domain with good associative learning (e.g., Heaton et al., 1998), both of which may operate on savant skill development. Perhaps the best way to assess this possibility would be to develop implicit learning tasks within existing savant domains and to develop implicit learning tasks within domains akin to savant domains but which would be completely novel both to the savants and to the comparison individuals, placing them on equal footing in learning this information. For example, utilising formulae for converting C° to F° could serve as a proxy for learning fairly simple regularities and algorithms and could assist in testing suggestions of hypersystemising.

Similarly novel was the assessment of time perception in ASD. Because there was limited literature on which to rely in choosing tasks, a basic examination of the three most commonly assessed forms of time perception (i.e., estimation, production, and reproduction) was decided upon. Nevertheless, extension of this work is warranted through alteration of the paradigm and recruitment of savants who are reported to possess a perfect appreciation for time passage. Based on one previous study utilising paradigms at finer time intervals (on the order of ms) than those used here, there is some indication that time perception in ASD may be impaired, if at all different, from that in matched controls (Szelag et al., 2004). Taking this research forward will assist in in/validating suppositions provided in this thesis regarding the pattern of time perception performance found in ASD. For example, the notion that good time reproduction amongst those with ASD reflects good rote memory in this group, could be assessed via correlational studies and/or experimental manipulation of the tasks used here.

IT as a measure of non-intellectual potential in ASD was partly validated through correlational analyses. This fast, low-level perceptual discrimination ability may indicate a unique underlying neural circuitry for those with ASD. Perhaps the IT task taps into the purported enhanced perception in ASD, particularly the ability to discriminate easily between different stimuli (Plaisted et al., 1998). Correlational studies between visual search and IT performance may provide clues here. Moreover, manipulation of the IT task for use in functional neuroimaging and eye-tracking paradigms may allow for a better understanding of how individuals with ASD, particularly those with MLD, score much better on this task than would be predicted based on their IQ scores.

Other general limitations within this thesis included methodological constraints. For example, a group study of savants by skill area would have provided more power concerning interpretations and findings, though most predictions in the present thesis were made to cut across all savant domains. Moreover, every effort was made to recruit non-ASD savants, but this proved extremely difficult. The only potential non-ASD savant participants that arose during recruitment were individuals with visual impairment (many of whom have associated symptoms that greatly overlap with the autism phenotype; Hobson, Lee, & Brown, 1999), which placed many constraints on the test battery making this option impractical. Moreover, a consistent confound between domain of talent and visual impairment was noted, since regardless of accompanying diagnosis (ASD or non-ASD), all encountered visually impaired savants were musicians. Therefore, future research should make every effort to recruit non-ASD savants when possible, which will make it easier to conclude which neuropsychological findings are due to ASD alone versus savant status. Finally, there were limitations in the clinical battery that should be improved in future research. Time constraints restricted IQ assessment to short-forms and there were no standard measures of symptomatology in the group study portion of the thesis. This second omission could be rectified in future with the use of a good ASD trait-based measure (akin to the AQ used in the case studies). This may provide specific links between aspects of the triad of impairment and savant skills, assuming one avoids the nontrivial dilemma of redundant assessment and/or circular reasoning (e.g., asking about "islets of ability" as part of the non-social aspect of the triad of impairment). Moreover, though the sample size in the group studies is comparable to most studies of this type reported in the extant literature, caution is warranted in extrapolating these results, particularly considering the wide age range and functioning levels of participants. Improvements could also be made to the experimental battery. In an effort to assess comprehensively

WCC, five tasks (many were brief) were utilised, which is somewhat unbalanced when compared to only one test of implicit learning, for example. And finally, in the evaluation of savant artwork, only two judges provided feedback. Because of the subjectivity of artwork evaluation, feedback from a larger number of judges may have provided more confidence in the skill level of the art savants reported here.

Despite these limitations, this thesis has provided novel findings, including the documentation of intact implicit sequence learning, time estimation, time production, and inspection time, but superior time reproduction, amongst individuals with ASD. Replication of previous findings from the ASD literature were also noted, such as superior segmentation ability, ability to isolate quickly and accurately hidden figures, and finally poor use of context in verbal material to inform sentence completions. Based on the newly reported findings in particular, expanding assessment of implicit learning in ASD to novel savant-like domains and further investigating what may underlie the time reproduction superiority in ASD are warranted. These future studies may replicate and expand the studies presented here and provide additional evidence as to the role these cognitive functions play in the development of savant skills in ASD.

9.4 Summary

The existence and nature of savant skills has long intrigued scientists; nevertheless, the savant syndrome now remains as much a mystery as it did when first described in the 18th century. When beginning this thesis, it seemed clear that a number of interacting factors contribute to savant skill development, though the raised incidence of these skills amongst individuals with ASD provided hints as to how to proceed in investigation. Modelling an approach taken by the seminal researchers in this field, O'Connor and Hermelin, this thesis aimed to examine a number of possible cognitive mechanisms that may contribute to savant skill development, particularly in the context of ASD. This thesis provided evidence linking WCC not only to ASD, but also to savant skills. Additionally, intact processing speed, implicit learning, and time perception (with some hint as to superior time reproduction) was demonstrated in both savant and nonsavant individuals with ASD. Therefore, it remains possible that a gateway model, wherein these functions need to be intact (at minimum), best describes access to and prevalence of savant skills amongst individuals with ASD. However, further work is needed to specify possible links between these (and other) cognitive mechanisms and savant skills as well as potential underlying biological mechanisms. Though this thesis did not provide definitive answers regarding the ontogeny of savant skills, several promising future directions for investigation were pinpointed.

References

Adrien, J. L., Fauer, M., Perrot, A., Hameury, L., Garrau, B., Barthelemy, C., & Savage, D. (1991). Autism and family home movies: Preliminary findings. *Journal of Autism and Developmental Disorders, 21*, 43-51.

Akshoomoff, N. A., Feroleto, C. C., Doyle, R. E., & Stiles, J. (2002). The impact of early unilateral brain injury on perceptual organization and visual memory. *Neuropsychologia, 40*, 539-561.

Alcantara, J. I., Weissblatt, E. J., Moore, B. C., & Bolton, P. F. (2004). Speech-in-noise perception in high-functioning individuals with autism or Asperger's syndrome. *Journal of Child Psychology and Psychiatry, 45*, 1107-1114.

American Psychiatric Association (1994). *The Diagnostic and Statistical Manual of Mental Disorders, 4th Edition* (DSM-IV). Washington, DC: Authors.

Anastasi, A., & Levee, R. F. (1960). Intellectual defect and musical talent: A case report. *American Journal of Mental Deficiency, 64*, 695-703.

Anderson, M. (1988). Inspection time, information processing and the development of intelligence. *British Journal of Developmental Psychology, 6*, 43-57.

Anderson, M. (1998). Mental retardation, general intelligence and modularity. *Learning and Individual Differences, 10*, 159-178.

Anderson, M. (2001). Annotation: conceptions of intelligence. *Journal of Child Psychology and Psychiatry, 42*, 287-98.

Anderson, M., & Miller, K. L. (1998). Modularity, mental retardation, and speed of processing. *Developmental Science, 1*, 239-245.

Anderson, M., O'Connor, N., & Hermelin, B. (1998). A specific calculating ability. *Intelligence, 26*, 383-403.

Anderson, N. B., & Rincover, A. (1982). The generality of overselectivity in developmentally disabled children. *Journal of Experimental Child Psychology, 34*, 217-230.

Aslin, R. N., & Smith, L. B. (1988). Perceptual development. *Annual Review of Psychology, 39*, 435-473.

Asperger, H. (1944). Die 'Autistischen Psychopathen' im Kindesalter. *Archiv für Psychiatrie und Nervenkrankheiten, 117*, 76–136.

Attwood, A. H., Frith, U., & Hermelin, B. (1988). The understanding and use of interpersonal gestures by autistic and Down's syndrome children. *Journal of Autism and Developmental Disorders, 18*, 241-257.

Atwell, J. A., Conners, F. A., & Merrill, E. C. (2003). Implicit and explicit learning in young adults with mental retardation. *American Journal on Mental Retardation, 108*, 56-68.

Baharloo, S., Service, S. K., Risch, N., Gitschier, J., & Freimer, N. B. (2000). Familial aggregation of absolute pitch. *American Journal of Human Genetics, 67*, 655-658.

Bailey, A., Bolton, P., Butler, L., LeCouteur, A., Murphy, M., Scott, S., Webb, T., & Rutter, M. (1993). Prevalence of the fragile X anomaly amongst autistic twins and singletons. *Journal of Child Psychology and Psychiatry, 34*, 673-688.

Bailey, A., LeCouteur, A., Gottesman, I., Bolton, P., Simonoff, E., Yuzda, F. Y., & Rutter, M. (1995). Autism as a strongly genetic disorder: Evidence from a British twin study. *Psychological Medicine, 25*, 63-77.

Bailey, A., Luthert, P., Dean, A., Harding, B., Janota, I., Montgomery, M., Rutter, M., & Lantos, P. (1998). A clinicopathological study of autism. *Brain, 121*, 889-905.

Bailey, A., Phillips, W., & Rutter, M. (1996). Autism: Towards an integration of clinical, genetic, neuropsychological, and neurobiological perspectives. *Journal of Child Psychology and*

Psychiatry, 37, 89-126.

Baird, G., Charman, T., Baron-Cohen, S., Cox, A., Swettenham, J., Wheelwright, S., & Drew, A. (2000). A screening instrument for autism at 18 months of age: a 6-year follow-up study. *Journal of the American Academy of Child & Adolescent Psychiatry, 39*, 694-702.

Baltaxe, C. A. (1984). Use of contrastive stress in normal, aphasic, and autistic children. *Journal of Speech & Hearing Research, 27*, 97-105.

Baranek, G. T. (1999). Autism during infancy: A retrospective video analysis of sensory-motor and social behaviors at 9-12 months of age. *Journal of Autism and Developmental Disorders, 29*, 213-224.

Baranek, G. T., David, F. J., Poe, M. D., Stone, W. L., & Watson, L. R. (2006). Sensory Experiences Questionnaire: discriminating sensory features in young children with autism, developmental delays, and typical development. *Journal of Child Psychology and Psychiatry, 47*, 591-601.

Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: constructing a unifying theory of ADHD. *Psychological Bulletin, 121*, 65-94.

Barkley, R. A., Edwards, G., Laneri, M., Fletcher, K., & Metevia, L. (2001). Executive functioning, temporal discounting, and sense of time in adolescents with attention deficit hyperactivity disorder (ADHD) and oppositional defiant disorder (ODD). *Journal of Abnormal Child Psychology, 29*, 541-556.

Barkley, R., Koplowitz, S., Anderson, T., & McMurray, M. (1997). Sense of time in children with ADHD: Effects of duration, distraction, and stimulant medication. *Journal of the International Neuropsychological Society, 3*, 359-369.

Barkley, R. A., Murphy, K. R., & Bush, T. (2001). Time perception and reproduction in young adults with attention deficit hyperactivity disorder. *Neuropsychology, 15*, 351-360.

Baron-Cohen, S. (2000). Theory of mind and autism: A fifteen year review. In S. Baron-Cohen, H. Tager-Flusberg, & D. J. Cohen (Eds.), *Understanding Other Minds: Perspectives from Developmental Cognitive Neuroscience* (pp.1-20). Oxford University Press.

Baron-Cohen, S. (2002). The extreme male brain theory of autism. *Trends in Cognitive Sciences, 6*, 248-254.

Baron-Cohen, S. (2006). The hyper-systemizing, assortative mating theory of autism. *Progress in Neuro-Psychopharmacology and Biological Psychiatry, 30*, 865-872.

Baron-Cohen, S., Allen, J., & Gillberg, C. (1992). Can autism be detected at 18 months? The needle, the haystack, and the CHAT. *British Journal of Psychiatry, 161*, 839-843.

Baron-Cohen, S., & Belmonte, M. K. (2005). Autism: A window onto the development of the social and the analytic brain. *Annual Review of Neuroscience, 28*, 109-126.

Baron-Cohen, S., & Hammer, J. (1997). Parents of children with Asperger syndrome: What is the cognitive phenotype? *Journal of Cognitive Neuroscience, 9*, 548-554.

Baron-Cohen, S., Jolliffe, T., Mortimore, C., & Robertson, M. (1997). Another advanced test of theory of mind: evidence from very high functioning adults with autism or Asperger syndrome. *Journal of Child Psychology & Psychiatry, 38*, 813-822.

Baron-Cohen, S., Knickmeyer, R. C., & Belmonte, M. K. (2005). Sex differences in the brain: implications for explaining autism. *Science, 310*, 819-823.

Baron-Cohen, S., Leslie, A. M., & Frith, U. (1985). Does the autistic child have a 'theory of mind'? *Cognition, 21*, 37-46.

Baron-Cohen, S., Richler, J., Bisarya, D., Gurunathan, N., & Wheelwright, S. (2003). The systemizing quotient: an investigation of adults with Asperger syndrome or high-functioning autism, and normal sex differences. *Philosophical Transactions of the Royal Society of London, 358*, 361-374.

Baron-Cohen, S., Tager-Flusberg, H., & Cohen, D. J. (2000). *Understanding other minds: Perspectives* *from developmental cognitive neuroscience (2^{nd} Ed.).* New York: Oxford University Press.

Baron-Cohen, S., & Wheelwright, S. (1999). 'Obsessions' in children with autism or Asperger syndrome: Content analysis in terms of core domains of cognition. *British Journal of Psychiatry, 175*, 484-490.

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The Autism-Spectrum Quotient (AQ): Evidence from Asperger syndrome/high-functioning autism, males and females, scientists and mathematicians. *Journal of Autism & Developmental Disorders, 31*, 5-17.

Baron-Cohen, S., Wheelwright, S., Spong, A., Scahill, V. & Lawson, J. (2001) Are intuitive physics and intuitive psychology independent?: A test with children with Asperger syndrome. *Journal of Developmental and Learning Disorders, 5*, 47-78.

Bartak, L., Rutter, M., & Cox, A. (1975). A comparative study of infantile autism and specific developmental receptive language disorder. I. The children. *British Journal of Psychiatry, 126*, 127-145.

Basso, M. R., Schefft, B. K., Ris, M. D., & Dember, W. N. (1996). Mood and global-local visual processing. *Journal of the International Neuropsychological Society, 2*, 249-255.

Bauman, M. L. (1991). Microscopic neuroanatomic abnormalities in autism. *Pediatrics, 87* (Suppl.), 791-796.

Bauman, M. L., & Kemper, T. L. (1985). Histoanatomic observations of the brain in early infantile autism. *Neurology, 35*, 866-874.

Bauminger, N., & Kasari, C. (2000). Loneliness and friendship in high-functioning children with autism. *Child Development, 71*, 447-456.

Behrmann, M., Avidan, G., Leonard, G. L., Kimchi, R., Luna, B., Humphreys, K., & Minshew, N. (2006). Configural processing in autism and its relationship to face processing. *Neuropsychologia, 44*, 110-129.

Bellugi, U., Birhle, A., Neville, H., Jernigan, Doherty, S., & Jernigan, T. (1992). Language, cognition, and brain organization in a neurodevelopmental disorder. In M. Gunnar & C. Nelson (Eds.), *Developmental behavioral neuroscience* (pp. 201-232). Hillsdale, NJ: Lawrence Erlbaum Associates.

Bellugi, U., Lichtenberger, L., Mills, D., Galaburda, A., & Korenberg, J. R. (1999). Bridging cognition, the brain and molecular genetics: Evidence from Williams syndrome. *Trends in Neurosciences, 22*, 197-207.

Belmonte, M. K., Allen, G., Beckel-Mitchener, A., Boulanger, L. M., Carper, R. A., & Webb, S. J. (2004). Autism and abnormal development of brain connectivity. *Journal of Neuroscience, 24*, 9228-9231.

Belmonte, M. K., & Yurgelun-Todd, D. A. (2003). Functional anatomy of impaired selective attention and compensatory processing in autism. *Cognitive Brain Research, 17*, 651-64.

Benbow, C. P. (1988). Sex differences in mathematical reasoning ability in intellectually talented preadolescents: Their nature, effects, and possible causes. *Behavioral and Brain Sciences, 11*, 169-232.

Bernstein, J. H., & Waber, D. P. (1996). *Developmental scoring system for the Rey–Osterreith Complex Figure: Professional manual.* Odessa, FL: Psychological Assessment Resources.

Bertenthal, B. I. (1996). Origins and early development of perception, action, and representation. *Annual Review of Psychology, 46*, 431-459.

Berument, S. K., Rutter, M., Lord, C., Pickles, A., & Bailey, A. (1999). Autism screening questionnaire: Diagnostic validity. *British Journal of Psychiatry, 175*, 444-451.

Beversdorf, D. Q., Smith, B. W., Crucian, G. P., Anderson, J. M., Keillor, J. M., Barrett, A. M., Hughes, J. D., Felopulos, G. J., Bauman, M. L., Nadeau, S. E., & Heilman, K. M. (2000). Increased discrimination of "false memories" in autism spectrum disorder. *Proceedings of* *the National Academy of Sciences, 97,* 8734-8737.

Binnie L., & Williams, J. (2003). Intuitive psychology and physics among children with autism and typically developing children. *Autism, 7,* 173-193.

Bhattcharya, J., & Petsche, H. (2005). Drawing on mind's canvas: differences in cortical integration patterns between artists and non-artists. *Human Brain Mapping, 26,* 1-14.

Block, R.A., Hancock, P. A., & Zakay, D. (2000). Sex differences in duration judgments: A meta-analytic review. *Memory and Cognition, 28,* 1333-1346.

Block, R.A., Zakay, D., & Hancock, P. A. (1999). Developmental changes in human duration judgments: A meta-analytic review. *Developmental Review, 19,* 183-211.

Boddaert, N., Barthelemy, C., Poline, J. B., Samson, Y., Brunelle, F., & Zilbovicius, M. (2005). Autism: functional brain mapping of exceptional calendar capacity. *British Journal of Psychiatry, 187,* 83-86.

Bondy, A., & Frost, L. (1994). The picture exchange communication system. *Focus on Autistic Behavior, 9,* 1-19.

Bonnel, A., Mottron, L., Peretz, I., Trudel, M., Gallun, E., & Bonnel, A. M. (2003). Enhanced pitch sensitivity in individuals with autism: a signal detection analysis. *Journal of Cognitive Neuroscience, 15,* 226-235.

Booth, R. D. L. (2006). *Local-global processing and cognitive style in autism spectrum disorder and typical development.* Unpublished PhD thesis, King's College, University of London.

Booth, R., Charlton, R., Hughes, C., & Happé, F. (2003). Disentangling weak coherence and executive dysfunction: Planning drawing in autism and attention deficit/hyperactivity disorder. *Philosophical Transactions of the Royal Society of London, 358,* 387-392.

Boucher, J., & Lewis, V. (1992). Unfamiliar face recognition in relatively able autistic children. *Journal of Child Psychology and Psychiatry, 33,* 843-859.

Bowler, D. M. (1992). "Theory of mind" in Asperger's syndrome. *Journal of Child Psychology and Psychiatry, 33,* 877-893.

Bowler, D. M., Gardiner, J. M., Grice, S., & Saavalainen, P. (2000). Memory illusions: False recall and recognition in adults with Asperger's syndrome. *Journal of Abnormal Psychology, 109,* 663-672.

Bowler, D. M., Matthews, N. J., & Gardiner, J. M. (1997). Asperger's syndrome and memory: Similarity to autism but not amnesia. *Neuropsychologia, 35,* 65-70.

Brady, P. T. (1970). Fixed-scale mechanism of absolute pitch. *Journal of the Acoustical Society of America, 48,* 883–887.

Brian, J. A., & Bryson, S. E. (1996). Disembedding performance and recognition memory in autism/PDD. *Journal of Child Psychology and Psychiatry, 37,* 865-872.

Brink, T. L. (1980). Idiot savant with unusual mechanical ability: An organic explanation. *American Journal of Psychiatry, 137,* 250-251.

Briskman, J., Happé, F., & Frith, U. (2001). Exploring the cognitive phenotype of autism: weak "central coherence" in parents and siblings of children with autism: II. Real-life skills and preferences. *Journal of Child Psychology and Psychiatry, 42,* 309-316.

Brocki, K. C., & Bohlin, G. (2004). Executive functions in children aged 6 to 13: A dimensional and developmental study. *Developmental Neuropsychology, 26,* 571-593.

Brosnan, M. J., Scott, F. J., Fox, S., & Pye, J. (2004). Gestalt processing in autism: failure to process perceptual relationships and the implications for contextual understanding. *Journal of Child Psychology and Psychiatry, 45,* 459-469.

Brown, C., & Dunn, W. (2002). *The adult sensory profile.* San Antonio, TX: Psychological Corporation.

Brown, S. W. (1985). Time perception and attention: The effects of prospective versus retrospective paradigms and task demands on perceived duration. *Perception and*

Psychophysics, 38, 115-124.

Brown, W. A., Cammuso, K., Sachs, H., Winklosky, B., Mullane, J., Bernier, R., Svenson, S., Arin, D., Rosen-Sheidley, B., & Folstein, S. E. (2003). Autism-related language, personality, and cognition in people with absolute pitch: Results of a preliminary study. *Journal of Autism and Developmental Disorder, 33*, 163-167.

Bryson, S. E., Clark, B. S., & Smith, I. M. (1988). First report of a Canadian epidemiological study of autistic syndromes. *Journal of Child Psychology and Psychiatry, 29*, 433-446.

Bryson, S. E., & Smith, I. M. (1998). Epidemiology of autism: Prevalence, associated characteristics, and implications for research and service delivery. *Mental Retardation and Developmental Disabilities Research Reviews, 4*, 97-103.

Burling, T. A., Sappington, J. T., & Mead, A. M. (1983). Lateral specialization of a perpetual calendar task by a moderately mentally retarded adult. *American Journal of Mental Deficiency, 88*, 326-328.

Burnette, C. P., Mundy, P. C., Meyer, J. A., Sutton, S. K., Vaughan, A. E., & Charak, D. (2005). Weak central coherence and its relations to theory of mind and anxiety in autism. *Journal of Autism and Developmental Disorders, 35*, 63-73.

Butler, M. G., Dasouki, M. J., Zhou, X. P., Talebizadeh, Z., Brown, M., Takahashi, T. N., Miles, J. H., Wang, C. H., Stratton, R., Pilarski, R., & Eng, C. (2005). Subset of individuals with autism spectrum disorders and extreme macrocephaly associated with germline PTEN tumour suppressor gene mutations. *Journal of Medical Genetics, 42*, 318-321.

Capps, L., Kasari, C., Yirmiya, N., & Sigman, M. (1993). Parental perception of emotional expressiveness in children with autism. *Journal of Consulting and Clinical Psychology, 61*, 475-484.

Capps, L., Sigman, M., & Mundy, P. (1994). Attachment security in children with autism. *Development and Psychopathology, 6*, 249-261.

Carlesimo, G. A., Marotta, L., & Vicari, S. (1997). Long-term memory in mental retardation: Evidence for a specific impairment in subjects with Down's syndrome. *Neuropsychologia, 35*, 71-79.

Ceponiene, R., Lepisto, T., Shestakova, A., Vanhala, R., Alku, P., Naatanen, R., & Yaguchi, K. (2003). Speech-sound-selective auditory impairment in children with autism: they can perceive but do not attend. *Proceedings of the National Academy of Sciences, 100*, 5567-5572.

Chakrabarti, S., & Fombonne, E. (2001). Pervasive developmental disorders in preschool children. *Journal of the American Medical Association, 285*, 3093-3099.

Chakrabarti, S., & Fombonne, E. (2005). Pervasive developmental disorders in preschool children: confirmation of high prevalence. *American Journal of Psychiatry, 162*, 1133-1141.

Charness, N., Clifton, J., & MacDonald, L. (1988). Case study of a musical "mono-savant": A cognitive-psychological focus. In L. K. Obler & D. Fein (Eds.), *The exceptional brain: Neuropsychology of talent and special abilities* (pp. 277-293). New York: Guilford.

Chase, W. G., & Ericsson, K. A. (1981). Skilled memory. In J. R. Anderson (Ed.), *Cognitive skills and their acquisition* (pp. 141-189). Hillsdale, NJ: Lawrence Erlbaum Associates.

Cohen, M. J., Hall, J., & Riccio, C. A. (1997). Neuropsychological profiles of children diagnosed as specific language impaired with and without hyperlexia. *Archives of Clinical Neuropsychology, 12*, 223-229.

Collins, D. W., & Kimura, D. (1997). A large sex difference on a two-dimensional mental rotation task. *Behavioral Neuroscience, 111*, 845-849.

Courchesne, E., Carper, R., & Akshoomoff, N. (2003). Evidence of brain overgrowth in the first year of life in autism. *Journal of the American Medical Association, 290*, 337-344.

Courchesne, E., Lincoln, A. J., Townsend, J. P., James, H. E., Akshoomoff, N. A., Saitoh, O., Egaas, B., Haas, R. H. & Schriebman, L. (1994). A new finding: Impairment in shifting attention in autistic and cerebellar patients. In S. H. Broman & J. Grafman (Eds.), *Atypical cognitive deficits in developmental disorders: Implications for brain function* (pp. 101-137). Hillsdale, NJ: Lawrence Erlbaum Associates.

Courchesne, E., Yeung-Courchesne, R., Press, G. A., Hesselink, J. R., & Jernigan, T. L. (1988). Hypoplasia of cerebellar vermal lobules VI and VII in autism. *New England Journal of Medicine, 318*, 1349-1354.

Cowan, R., O'Connor, N., & Samella, K. (2001). Why and how people of limited intelligence become calendrical calculators. *Infancia y Aprendizaje, 24*, 53-65.

Cowan, R., O'Connor, N., & Samella, K. (2003). The skills and methods of calendrical savants. *Intelligence, 31*, 51-65.

Cowan, R., Stainthorp, R., Kapnogianni S., & Anastasiou, M. (2004). The development of calendrical skills. *Cognitive Development, 19*, 169-178.

Cox, M., & Eames, K. (1999). Contrasting styles of drawing in gifted individuals with autism. Autism, 3, 397-409.

Crawford, J. R., & Garthwaite, P. H. (2004) Statistical methods for single-case research in neuropsychology: Comparing the slope of a patient's regression line with those of a control sample. *Cortex, 40*, 533-548.

Crawford, J. R., & Garthwaite, P. H. (2005). Testing for suspected impairments and dissociations in single-case studies in neuropsychology: evaluation of alternatives using monte carlo simulations and revised tests for dissociations. *Neuropsychology, 19*, 318-331.

Crawford, J. R. & Howell, D. C. (1998). Comparing an individual's test score against norms derived from small samples. *The Clinical Neuropsychologist*, *12*, 482-486.

Crawford, J. R., Howell, D. C., & Garthwaite, P. H. (1998). Payne and Jones revisited: Estimating the abnormality of test score differences using a modified paired samples *t*-test. *Journal of Clinical and Experimental Neuropsychology, 20*, 898-905.

Cyr, J. J., & Brooker, B. H. (1984). Use of appropriate formulas for selecting WAIS-R short forms. *Journal of Consulting and Clinical Psychology, 52*, 903-905.

Damasio, A. R., & Maurer, R. G. (1978). A neurological model for childhood autism. *Archives of Neurology, 35*, 777-786.

Dawson, G., & Lewy, A. (1989). Arousal, attention, and the social-emotional impairments of individuals with autism. In G. Dawson (Ed.), *Autism: Nature, diagnosis and treatment* (pp. 49-74). New York: Guilford Press.

Dawson, G., Meltzoff, A. N., Osterling, J., Rinaldi, J., & Brown, E. (1998). Children with autism fail to orient to naturally occurring social stimuli. *Journal of Autism and Developmental Disorders, 28*, 479-485.

de Gelder, B., Vroomen, J., & van der Heide, L. (1991). Face recognition and lip-reading in autism. *European Journal of Cognitive Psychology, 3*, 69-86.

de Jonge, M. V., Kemner, C., & van Engeland, H. (2006). Superior disembedding performance of high-functioning individuals with autism spectrum disorders and their parents: The need for subtle measures. *Journal of Autism and Developmental Disorders, 36*, 677-683.

Dorman, C. (1991). Exceptional calendar calculation ability after early left hemispherectomy. *Brain and Cognition, 15*, 26-36.

Dorris, L., Espie, C. A., Knott, F., & Salt, J. (2004). Mind-reading difficulties in the siblings of people with Asperger's syndrome: evidence for a genetic influence in the abnormal development of a specific cognitive domain. *Journal of Child Psychology & Psychiatry, 45*, 412-418.

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

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

Drayna, D., Manichaikul, A., de Lange, M., Snieder, H., & Spector, T. (2001). Genetic correlates of musical pitch recognition in humans. *Science, 291*, 1969-1972.

Duckett, J. M. (1976). *Idiot savants: Super specialization in mentally retarded persons.* Unpublished Ph.D. Dissertation, University of Texas at Austin.

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

Dunn, M., Gomes, H., & Sebastian, M. (1996). Prototypicality of responses of autistic, language disordered, and normal children in a word fluency task. *Child Neuropsychology, 2*, 99-108.

Dykens, E. M. (2002). Are jigsaw puzzle skills 'spared' in persons with Prader-Willi syndrome? *Journal of Child Psychology and Psychiatry, 43*, 343-352.

Dykens, E. M., & Volkmar, F. R. (1997). Medical conditions associated with autism. In D. J. Cohen & F. R. Volkmar (Eds.), *Handbook of autism and pervasive developmental disorders* (2nd ed., pp. 388-410). New York: John Wiley & Sons.

Elliott, C. (1996). *British Ability Scales II.* Windsor, UK: NFER Nelson.

Ellis, N. R., Palmer, R. L., & Reeves, C. L. (1988). Developmental and intellectual differences in frequency processing. *Developmental Psychology, 24*, 38-45.

Ellis, N. R., Woodley-Zanthos, P., & Dulaney, C. L. (1989). Memory for spatial location in children, adults, and mentally retarded persons. *American Journal of Mental Retardation, 93*, 521-526.

Ericsson, K. A., & Charness, N. (1994). Expert performance: Its structure and acquisition. *American Psychologist, 49*, 725-747.

Ericsson, K. A., & Faivre, I. A. (1988). What's exceptional about exceptional abilities? In L. K. Obler & D. Fein (Eds.), *The exceptional brain: Neuropsychology of talent and special abilities* (pp. 436-473). New York: Guilford.

Ermer, J., & Dunn, W. (1998). The sensory profile: A discriminant analysis of children with and without disabilities. *American Journal of Occupational Therapy, 52*, 283-290.

Esch, B. E., & Carr, J. E. (2004). Secretin as a treatment for autism: A review of the evidence. *Journal of Autism and Developmental Disorders, 34*, 543-556.

Eysenck, H. J. (1988). The concept of "intelligence": Useful or useless? *Intelligence, 12*, 1–16.

Farran, E. K., Jarrold, C., & Gathercole, S. E. (2003). Divided attention, selective attention and drawing: processing preferences in Williams syndrome are dependent on the task administered. *Neuropsychologia, 41*, 676-687.

Feinstein, C., & Reiss, A. L. (1998). Autism: The point of view from fragile X studies. *Journal of Autism and Developmental Disorders, 28*, 393-405.

Fine, J., Bartolucci, G., Ginsberg, G., & Szatmari, P. (1991). The use of intonation to communicate in pervasive developmental disorders. *Journal of Child Psychology and Psychiatry, 32*, 771-782.

Fletcher, J., Maybery, M. T., & Bennett, S. (2000). Implicit learning differences: A question of developmental level? *Journal of Experimental Psychology: Learning, Memory and Cognition, 26*, 246-252.

Fodor, J. A. (1983). *The modularity of mind.* Cambridge, MA: MIT Press.

Foerstl, J. (1989). Early interest in the idiot savant. *American Journal of Psychiatry, 146*, 566.

Folstein, S., & Rutter, M. (1977). Genetic influences and infantile autism. *Nature, 265*, 726-728.

Fombonne, E. (1999). The epidemiology of autism: A review. *Psychological Medicine, 29*, 769-786.

Fombonne, E., & Chakrabarti, S. (2001). No evidence for a new variant of measles-mumps-rubella-induced autism. *Pediatrics, 108*, E58.

Fombonne, E., Du Mazaubrun, C., Cans, C., & Grandjean, H. (1997). Autism and associated medical disorders in a French epidemiological survey. *Journal of the American Academy of Child and Adolescent Psychiatry, 36*, 1561-9.

Fombonne, E., Roge, B., Claverie, J., Courty, S., & Fremolle, J. (1999). Microcephaly and macrocephaly in autism. *Journal of Autism and Developmental Disorders, 29*, 113-119.

Fombonne, E., Zakarian, R., Bennett, A., Meng, L., & McLean-Heywood, D. (2006). Pervasive developmental disorders in Montreal, Quebec, Canada: prevalence and links with immunizations. *Pediatrics, 118*, e139-e150.

Fox, R., & Oross, S. (1990). Mental retardation and perception of global motion. *Perception & Psychophysics, 48*, 252-258.

Foxton, J. M., Stewart, M. E., Barnard, L., Rodgers, J., Young, A. H., O'Brien, G., & Griffiths, T. D. (2003). Absence of auditory 'global interference' in autism. *Brain, 126*, 2703-2709.

Frith, U. (1989). *Autism: Explaining the enigma.* Oxford: Basil Blackwell.

Frith, U. (1991). Asperger and his syndrome. In U. Frith (Ed.), *Autism and Asperger syndrome* (pp. 1–36). Cambridge, UK: Cambridge University Press.

Frith, U. (2001). What framework should we use for understanding developmental disorders? *Developmental Neuropsychology, 20*, 555-563.

Frith, U., & Baron-Cohen, S. (1987). Perception in autistic children. In D. J. Cohen & A. M. Donnellan (Eds.), *Handbook of Autism and Pervasive Development Disorders* (pp.85-102). New York: John Wiley & Sons.

Frith, U., & Happé, F. (1998). Why specific developmental disorders are not specific: On-line and developmental effects in autism and dyslexia. *Developmental Science, 1*, 267-272.

Frith, U., & Snowling, M. (1983). Reading for meaning and reading for sound in autistic and dyslexic children. *British Journal of Developmental Psychology, 1*, 329-342

Gabriels, R. L., Cuccaro, M. L., Hill, D. E., Ivers, B. J., & Goldson, E. (2005). Repetitive behaviors in autism: relationships with associated clinical features. *Research in Developmental Disabilities, 26*, 169-181.

Gardiner, J. M., Bowler, D. M., & Grice, S. J. (2003). Further evidence of preserved priming and impaired recall in adults with Asperger's syndrome. *Journal of Autism and Developmental Disorders, 33*, 259-269.

Gardner, H. (1983). *Frames of mind: The theory of multiple intelligences.* New York: Harper & Row.

Garfield, J. L., Peterson, C. C., & Perry, T. (2001). Social cognition, language acquisition and the development of theory of mind. *Mind & Language, 16*, 494-541.

Gepner, B., de Gelder, B., & de Schonen, S. (1996). Face processing in autistics: Evidence for a generalised deficit? *Child Neuropsychology, 2*, 123-139.

Gepner, B., Mestre, D., Masson, G., & de Schonen, S. (1995). Postural effects of motion vision in young autistic children. *Neuroreport, 6*, 1211-1214.

Gernsbacher, M. A., Dawson, M., & Goldsmith, H. H. (2005). Three reasons not to believe in an autism epidemic. *Current Directions in Psychological Science, 14*, 55-58.

Gersten, R. (1983). Stimulus overselectivity in autistic, trainable mentally retarded, and non-handicapped children: comparative research controlling chronological (rather than mental) age. *Journal of Abnormal Child Psychology, 11*, 61-75.

Gervais, H., Belin, P., Boddaert, N., Leboyer, M., Coez, A., Sfaello, I., Barthelemy, C., Brunelle, F., Samson, Y., & Zilbovicius, M. (2004). Abnormal cortical voice processing in autism. *Nature Neuroscience, 7*, 801-802.

Geschwind, N., & Galaburda, A. (1987). *Cerebral lateralization: Biological mechanisms, associations, and pathology.* Cambridge, MA: MIT Press.

Giedd, J. N. (2004). Structural magnetic resonance imaging of the adolescent brain. *Annals of the New York Academy of Sciences, 1021*, 77-85.

Gillberg, C. (1986). Onset at age 14 of a typical autistic syndrome. *Journal of Autism and Developmental Disorder, 16*, 369-375.

Gillberg, C. (1990). Autism and pervasive developmental disorders. *Journal of Child Psychology and Psychiatry, 31*, 99-119.

Gillberg, C. (1991). Autistic syndrome with onset at age 31 years: Herpes encephalitis as a possible model for childhood autism. *Developmental Medicine and Child Neurology, 33*, 920-924.

Gillberg, C. (1995). The prevalence of autism and autism spectrum disorders. In F. C. Verhulst & H. M. Koot (Eds.), *The epidemiology of child and adolescent psychopathology* (pp. 227-257). London: Oxford University Press.

Gillberg, C., & Coleman, M. (1996). Autism and medical disorders: a review of the literature. *Developmental Medicine & Child Neurology, 38*, 191-202.

Gillberg, C., & Wahlström, J. (1985). Chromosome abnormalities in infantile autism and other childhood psychoses: A population study of 66 cases. *Developmental Medicine and Child Neurology, 27*, 293-304.

Goldfarb, W. (1956). Receptor preferences in schizophrenic children. *Archives of Neurology and Psychiatry, 76*, 643-652.

Goldstein, G., Beers, S. R., Siegel, D. J., & Minshew, N. J. (2001). A comparison of WAIS-R profiles in adults with high-functioning autism or differing subtypes of learning disability. *Applied Neuropsychology, 8*, 148-154.

Golombok, S., & Rust, J. (1992). The UK Revision. In D. Wechsler (Ed.), *The Manual of the Wechsler Intelligence Scale for Children - 3rd Revision (WISC-III UK)*. The Psychological Corporation: London.

Gonzalez-Garrido, A. A., Ruiz-Sandova, J. L., Gomez-Velazquez, F. R., deAlba, J. L., & Villasenor-Cabrera, T. (2002). Hypercalculia in savant syndrome: central executive failure? *Archives of Medical Research, 33*, 586-589.

Goodman, R. (1989). Infantile autism: A syndrome of multiple primary deficits? *Journal of Autism and Developmental Disorders, 19*, 409-424.

Grandin, T., & Scariano, M. (1986). *Emergence: Labelled autistic.* Novato, CA: Arena.

Green, A. J., & Gilhooly, K. J. (1992). Empirical advances in expertise research. In M. T. Keane & K. J. Gilhooly (Eds.), *Advances in the Psychology of Thinking.* London, UK: Harvester Wheatsheaf.

Grier, J. B. (1971). Nonparametric indexes for sensitivity and bias: Computing formulas. *Psychological Bulletin, 75*, 424-429.

Griffith, E. M., Pennington B. F., Wehner E. A., & Rogers, S. J. (1999). Executive functions in young children with autism. Child Development, 70, 817-832.

Grigorenko, E. L., Klin, A., & Volkmar, F. (2003). Annotation: Hyperlexia: disability or superability? *Journal of Child Psychology and Psychiatry, 44*, 1079-1091.

Grudnik, J. L., & Kranzler, J. H. (2001). Meta-analysis of the relationship between intelligence and inspection time. *Intelligence, 29*, 523-535.

Guess, D., & Carr, E. (1991). Emergence and maintenance of stereotypy and self-injury. *American Journal on Mental Retardation, 96*, 299-319.

Hadjikhani, N., Joseph, R. M., Snyder, J., Chabris, C. F., Clark, J., Steele, S., McGrath, L., Vangel, M., Aharon, I., Feczko, E., Harris, G. J., & Tager-Flusberg, H. (2004). Activation of the fusiform gyrus when individuals with autism spectrum disorder view faces. *Neuroimage, 22*, 1141-1150.

Happé, F. G. E. (1993). Communicative competence and theory of mind in autism: A test of relevance theory. *Cognition, 48*, 101-19.

Happé, F. G. E. (1994a). An advanced test of theory of mind: Understanding of story characters' thoughts and feelings by able autistic, mentally handicapped, and normal children and adults. *Journal of Autism and Developmental Disorders, 24*, 129-154.

Happé, F. G. E. (1994b). Wechsler IQ profile and theory of mind in autism: A research note. *Journal of Child Psychology and Psychiatry, 35*, 1461-1471.

Happé, F. G. E. (1995). The role of age and verbal ability in the theory of mind task performance of subjects with autism. *Child Development, 66*, 843-855.

Happé, F. G. E. (1996). Studying weak central coherence at low levels: children with autism do not succumb to visual illusions. A research note. *Journal of Child Psychology & Psychiatry, 37*, 873-877.

Happé, F. G. E. (1997). Central coherence and theory of mind in autism: Reading homographs in context. *British Journal of Developmental Psychology, 15*, 1-12.

Happé, F. (1999). Autism: Cognitive deficit or cognitive style? *Trends in Cognitive Sciences, 3*, 216-222.

Happé, F., & Booth, R. (in preparation). Sentence completion: A simple test of weak coherence in typical development, autism spectrum disorders and attention deficit/hyperactivity disorder.

Happé, F., Briskman, J., & Frith, U. (2001). Exploring the cognitive phenotype of autism: weak "central coherence" in parents and siblings of children with autism: I. Experimental tests. *Journal of Child Psychology & Psychiatry, 42*, 229-307.

Happé, F., Ehlers, S., Fletcher, P., Frith U., Johansson, M., Gillberg, C., Dolan, R., Frackowiak, R., & Frith, C. (1996). 'Theory of mind' in the brain. Evidence from a PET scan study of Asperger syndrome. *Neuroreport, 8*, 197-201.

Happé, F., & Frith, U. (1996). The neuropsychology of autism. *Brain, 119*, 1377-1400.

Happé, F., & Frith, U. (2006). The weak coherence account: Detail-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders, 36*, 1-21.

Hardan, A. Y., Minshew, N. J., Harenski, K., & Keshavan, M. S. (2001). Posterior fossa magnetic resonance imaging in autism. *Journal of the American Academy of Child and Adolescent Psychiatry, 40*, 666-672.

Hardan, A. Y., Minshew, N. J., & Keshavan, M. S. (2000). Corpus callosum size in autism. *Neurology, 55*, 1033-1036.

Harris, S. R., MacKay, L. L., & Osborn, J. A. (1995). Autistic behaviors in offspring of mothers abusing alcohol and other drugs: A series of case reports. *Alcoholism: Clinical & Experimental Research, 19*, 660-665.

Hauck, M., Fein, D., Maltby, N., Waterhouse, L., & Feinstein, C. (1998). Memory for faces in children with autism. *Child Neuropsychology, 4*, 187-198.

Heaton, P. (2003). Pitch memory, labelling and disembedding in autism. *Journal of Child Psychology and Psychiatry, 44*, 543-551.

Heaton, P., Hermelin, B., & Pring, L. (1998). Autism and pitch processing: A precursor for savant musical ability. *Music Perception, 15*, 291-305.

Heaton, P., Pring, L., & Hermelin, B. (1999). A pseudo-savant: A case of exceptional musical splinter skills. *Neurocase, 5*, 503-509.

Heavey, L. J. (1997). *Memory in the calendar calculating savant.* Unpublished Ph.D. thesis, Goldsmith's College, University of London.

Heavey, L. (2003). Arithmetical savants. In A. Baroody & A. Dowker (Eds.), *The development of arithmetic concepts and skills: Recent research and theory.* Oxford: Oxford University Press

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

Herlitz, A., Nilsson, L. G., & Backman, L. (1997). Gender differences in episodic memory. *Memory and Cognition, 25*, 801-811.

Hermelin, B. (2001). *Bright splinters of the mind: A personal story of research with autistic savants.* Kingsley: London.

Hermelin, B., & O'Connor, N. (1964). Effects of sensory input and sensory dominance on severely disturbed, autistic children and on subnormal controls. *British Journal of Psychology,* *55*, 201-206.

Hermelin, B., & O'Connor, N. (1967). Remembering of words by psychotic and subnormal children. *British Journal of Psychology, 58*, 213-218.

Hermelin, B., & O'Connor, N. (1970). *Psychological experiments with autistic children.* Oxford: Pergamon Press.

Hermelin, B., & O'Connor, N. (1983). The idiot savant: flawed genius or clever Hans? *Psychological Medicine, 13*, 479-481.

Hermelin, B., & O'Connor, N. (1986). Idiot savant calendrical calculators: Rules and regularities. *Psychological Medicine, 16*, 885-893.

Hermelin, B., & O'Connor, N. (1990a). Factors and primes: A specific numerical ability. *Psychological Medicine, 20*, 163-169.

Hermelin, B., & O'Connor, N. (1990b). Art and accuracy: The drawing ability of idiot-savants. *Journal of Child Psychology and Psychiatry, 31*, 217-228.

Hermelin, B., O'Connor, N., Lee, S., & Treffert, D. (1989). Intelligence and musical improvisation. *Psychological Medicine, 19*, 447-457.

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

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

Herrnstein, M., & Murray, C. (1994). *The bell curve.* New York: Free Press.

Hill, A. L. (1974). Idiot savants: A categorization of abilities. *Mental Retardation, 12*, 12-13.

Hill, A. L. (1975). An investigation of calendar calculating by an idiot savant. *American Journal of Psychiatry, 132*, 557-560.

Hill, A. L. (1977). Idiot savants: Rate of incidence. *Perceptual and Motor Skills, 44*, 161-162.

Hill, A. L. (1978). Savants: Mentally retarded individuals with special skills. In N. Ellis (Ed.), *International review of research in mental retardation* (pp. 277-298). New York: Academic Press.

Hindermann, F. (1982). *Katzen.* Zurich, Switzerland: Manesse Verlag.

Hirstein, W., Iversen, P., & Ramachandran, V. S. (2001). Autonomic responses of autistic children to people and objects. *Proceedings of the Royal Society of London, 268*, 1883-1888.

Ho, E., Tsang, A., & Ho, D. (1991). An investigation of the calendar calculation ability of a Chinese calendar savant. *Journal of Autism and Developmental Disorder, 21*, 315-327.

Hobson, R. P., Lee, A., & Brown, R. (1999). Autism and congenital blindness. *Journal of Autism and Developmental Disorders, 29*, 45-56.

Hobson, R. P., Ouston, J., & Lee, A. (1988). What's in a face? The case of autism. *British Journal of Psychology, 79*, 441-453.

Hoffman, E. (1971). The idiot-savant: A case report and a review of explanations. *Mental Retardation, 9*, 18-21.

Hoffman, E., & Reeves, R. (1979). An idiot savant with unusual mechanical ability. *American Journal of Psychiatry, 136*, 713-714.

Honda, H, Shimizu, Y., & Rutter, M. (2005). No effect of MMR withdrawal on the incidence of autism: a total population study. *Journal of Child Psychology and Psychiatry, 46*, 572-579.

Hooper, H. E. (1958). *The Hooper Visual Organization Test manual.* Los Angles, CA: Western Psychological Services.

Hornstein, A. D. & Rotter, G. S. (1969). Research methodology in temporal perception. *Journal of Experimental Psychology, 79*, 561-564.

Horwitz, W. A., Kestenbaum, C., Person, E., & Jarvik, L. (1965). Identical twin-"idiot savants"-calendar calculators. *American Journal of Psychiatry, 121*, 1075-1079.

Hou, C., Miller, B. L., Cummings, J. L., Goldberg, M., Mychack, P., Bottino, V., & Benson, D.

F. (2000). Artistic savants. *Neuropsychiatry, Neuropsychology, and Behavioral Neurology, 13*, 29-38.

Howe, M. (1989). *Fragments of genius: The strange feats of idiot savants.* London: Routledge.

Howe, M. J. A., Davidson, J. W., & Sloboda, J. A. (1998). Innate talents: Reality or myth? *Behavioral and Brain Sciences, 21*, 399-442.

Howe, M. J., & Smith, J. (1988). Calendar calculating in 'idiots savants': how do they do it? *British Journal of Psychology, 79*, 371-386.

Howlin, P. (1998). Practitioner review: psychological and educational treatments for autism. *Journal of Child Psychology & Psychiatry, 39*, 307-322.

Howlin, P. (2003). Can early interventions alter the course of autism? In G. Bock & J. Goode (Eds.), *Autism: Neural basis and treatment possibilities* (pp. 250-265). New York: John Wiley & Sons.

Howlin, P., Goode, S., Hutton, J., & Rutter, M. (2004). Adult outcome for children with autism. *Journal of Child Psychology & Psychiatry, 45*, 212-229.

Hughes, C., Leboyer, M., & Bouvard, M. (1997). Executive function in parents of children with autism. *Psychological Medicine, 27*, 209-220.

Hughes, C., Plumet, M. H., & Leboyer, M. (1999). Towards a cognitive phenotype for autism: Increased prevalence of executive dysfunction and superior spatial span amongst siblings of children with autism. *Journal of Child Psychology and Psychiatry, 40*, 705-718.

Hughes, C., & Russell, J. (1993). Autistic children's difficulty with mental disengagement from an object: Its implications for theories of autism. *Developmental Psychology, 29*, 498-510.

Hurst, L. C., & Mulhall, D. J. (1988). Another calendar savant. *British Journal of Psychiatry, 152*, 274-277.

Ingram, J. L., Peckham, S. M., Tisdale, B., & Rodier, P. M. (2000). Prenatal exposure of rats to valproic acid reproduces the cerebellar anomalies associated with autism. *Neurotoxicology & Teratology, 22*, 319-24.

Ivry, R. B., & Justus, T. C. (2001). Comment: A neural instantiation of the motor theory of speech perception. *Trends in Neurosciences, 24*, 513-515.

Jackson, G. M., Jackson, S. R., Harrison, J., Henderson, L., & Kennard, C. (1995). Serial reaction time learning and Parkinson's disease: evidence for a procedural learning deficit. *Neuropsychologia, 33*, 577-593.

Jackson, M., & Warrington, E. K. (1986). Arithmetic skills in patients with unilateral cerebral lesions. *Cortex, 22*, 611-620.

Jarrold, C., & Russell, J. (1997). Counting abilities in autism: Possible implications for Central Coherence theory. *Journal of Autism and Developmental Disorders, 27*, 25-37.

Jensen, A. R. (1982). Reaction time and psychometric g. In H. J. Eysenck (Ed.), *A model for intelligence* (pp. 93-132). Berlin: Springer-Verlag.

Johnson, S. C., Lowery, N., Kohler, C., & Turetsky, B. I. (2005). Global-local visual processing in schizophrenia: evidence for an early visual processing deficit. *Biological Psychiatry, 58*, 937-946.

Jolliffe, T. & Baron-Cohen, S. (1997). Are people with autism and Asperger syndrome faster than normal on the Embedded Figures Test? *Journal of Child Psychology & Psychiatry, 38*, 527-534.

Jolliffe, T., & Baron-Cohen, S. (1999). A test of central coherence theory: Linguistic processing in high-functioning adults with autism or Asperger syndrome: Is local coherence impaired? Cognition, 71, *149-185.*

Jolliffe, T., & Baron-Cohen, S. (2000). Linguistic processing in high-functioning adults with autism or Asperger's syndrome: Is global precedence impaired? *Psychological Medicine, 30*, 1169-1187.

Jolliffe, T., & Baron-Cohen, S. (2001a). A test of central coherence theory: Can adults with high-functioning autism or Asperger syndrome integrate objects in context? Visual Cognition, 8, *67-101.*

Jolliffe, T., & Baron-Cohen, S. (2001b). A test of central coherence theory: Can adults with high-functioning autism or Asperger syndrome integrate fragments of an object? Cognitive Neuropsychiatry, 6, *193-216.*

Johnson, S. C., Lowery, N., Kohler, C., & Turetsky, B. I. (2005). Global-local visual processing in schizophrenia: evidence for an early visual processing deficit. *Biological Psychiatry, 58*, 937-946.

Kamio, Y., & Toichi, M. (2000) Dual access to semantics in autism: Is pictorial access superior to verbal access? *Journal of Child Psychology and Psychiatry, 41*, 859-867.

Kanner, L. (1943). Autistic disturbances of affective contact. *Nervous Child, 2*, 217-250.

Kanner, L. (1951). The conception of wholes and parts in early infantile autism. *American Journal of Psychiatry, 108*, 23-26.

Kapur, N. (1996). Paradoxical facilitated function in brain-behaviour research: A critical review. *Brain, 119*, 1775-1790.

Karmiloff-Smith, A. (1998). Development itself is the key to understanding developmental disorders. *Trends in Cognitive Sciences, 2*, 389-398.

Kelly, S. J., Macaruso, P., & Sokol S. M. (1997). Mental calculation in an autistic savant: A case study. *Journal of Clinical and Experimental Neuropsychology, 19*, 172-184.

Kenworthy, L. E., Black, D. O., Wallace, G. L., Ahluvalia, T., Wagner, A. E., & Sirian, L. M. (2005). Disorganization: The forgotten executive dysfunction in high-functioning autism spectrum disorders. *Developmental Neuropsychology*, 28, 809-827.

Kerns, K., McInerney, R., & Wilde, N. (2001). Time reproduction, working memory, and behavioral inhibition in children with ADHD. *Child Neuropsychology, 7*, 21-31.

Kim, J. A., Szatmari, P., Bryson, S. E., Streiner, D. L., & Wilson, F. J. (2000). The prevalence of anxiety and mood problems among children with autism and Asperger syndrome. *Autism, 4*, 117-132.

Kimchi, R. (1990). Children's perceptual organisation of hierarchical visual patterns. *European Journal of Cognitive Psychology, 2*, 133-149.

Kimchi, R. (1992). Primacy of wholistic processing and the global/local paradigm: A critical review. *Psychological Bulletin, 112*, 24-38.

Kinsbourne, M. (1987). Cerebral-brainstem interactions in infantile autism. In E. Schopler & G. Mesibov (Eds.), *Neurobiological Theories of Arousal and Autism*. New York: Plenum.

Kirkham, N. Z., Slemmer, J. A., & Johnson, S. P. (2002). Visual statistical learning in infancy: Evidence for a domain general learning mechanism. *Cognition, 83*, B35-B42.

Klin, A. (1991). Young autistic children's listening preferences in regard to speech: A possible characterization of the symptom of social withdrawal. *Journal of Autism and Developmental Disorders, 21*, 29-42.

Klin, A. (2000). Attributing social meaning to ambiguous visual stimuli in higher-functioning autism and Asperger syndrome: The Social Attribution Task. *Journal of Child Psychology and Psychiatry, 41*, 831-846.

Klin A., Volkmar, F. R., Sparrow, S. S., Cicchetti, D. V., & Rourke, B. P. (1995). Validity and neuropsychological characterization of Asperger syndrome: convergence with nonverbal learning disabilities syndrome. *Journal of Child Psychology and Psychiatry, 36*, 1127-1140.

Klinger, L. G., & Dawson, G. (2001). Prototype formation in autism. *Development & Psychopathology, 13*, 111-124.

Klinger, L.G., Lee, J.M., Bush, D., Klinger, M.R., & Crump, S.E. (2001, April). *Implicit learning in autism: Artificial grammar learning.* Poster presented at the Society for Research in Child

Development, Biennial Meeting, Minneapolis, Minnesota.

Knickmeyer RC, Wheelwright S, Taylor K, Raggatt P, Hackett G, Baron-Cohen S. (2005). Gender-typed play and amniotic testosterone. *Developmental Psychology, 41*, 517-528.

Koegel, R. L., & Lovaas, O. I. (1978). Comments on autism and stimulus overselectivity. *Journal of Abnormal Psychology, 87*, 563-565.

Kolers, P. A. (1983). Perception and representation. *Annual Review of Psychology, 34*, 129-166.

Komatsu, S., Naito, M., & Fuke, T. (1996). Age-related and intelligence-related differences in implicit memory: effects of generation on a word-fragment completion test. *Journal of Experimental Child Psychology, 62*, 151-172.

Kranzler, J. H., & Jensen, A. R. (1989). Inspection time and intelligence: A meta-analysis. *Intelligence, 13*, 329-347.

Kuntsi, J., Oosterlaan, J., & Stevenson, J. (2001). Psychological mechanisms in hyperactivity: I. Response inhibition deficit, working memory impairment, delay aversion, or something else? *Journal of Child Psychology and Psychiatry, 42*, 199-210.

Lainhart, J. E., Piven, J., Wzorek, M., Landa, R., Santangelo, S. L., Coon, H., & Folstein, S. E. (1997). Macrocephaly in children and adults with autism. *Journal of the American Academy of Child and Adolescent Psychiatry, 36*, 282-290.

Landa, R., Wzorek, M., Piven, J., Folstein, S. E., & Isaacs, C. (1991). Spontaneous narrative discourse characteristics of parents of autistic individuals. *Journal of Speech and Hearing Research, 34*, 1339-1345.

Langdell, T. (1978). Recognition of faces: an approach to the study of autism. *Journal of Child Psychology and Psychiatry, 19*, 255-268.

Lawrence, K., Campbell, R., Swettenham, J., Terstegge, J., Akers, R., Coleman, M., & Skuse, D. (2003). Interpreting gaze in Turner syndrome: impaired sensitivity to intention and emotion, but preservation of social cueing. *Neuropsychologia, 41*, 894-905.

Lawson, J., Baron-Cohen, S., & Wheelwright, S. (2004). Empathising and systemising in adults with and without Asperger Syndrome. *Journal of Autism and Developmental Disorders, 34*, 301-310.

Lee, A., Hobson, R., P., & Chiat, S. (1994). I, you, me, and autism: An experimental study. *Journal of Autism and Developmental Disorders, 24*, 155-76.

Leekam, S. R., & Prior, M. (1994). Can autistic children distinguish lies from jokes? A second look at second-order belief attribution. *Journal of Child Psychology & Psychiatry, 35*, 901-915.

Levitin, D. J. (2005). Musical behavior in a neurogenetic developmental disorder: evidence from Williams syndrome. *Annals of the New York Academy of Sciences, 1060*, 325-334.

Levitin, D. J., Cole, K., Chiles, M., Lai, Z., Lincoln, A., & Bellugi, U. (2004). Characterizing the musical phenotype in individuals with Williams Syndrome. *Child Neuropsychology, 10*, 223-247.

Levitin, D. J., Cole, K., Lincoln, A., & Bellugi, U. (2005). Aversion, awareness, and attraction: investigating claims of hyperacusis in the Williams syndrome phenotype. *Journal of Child Psychology and Psychiatry, 46*, 514-523.

Lewicki, P., Hill, T., & Czyzewska, M. (1992). Nonconscious acquisition of information. *American Psychologist, 47*, 796-801.

Lincoln, A. J., Allen, M. H., & Kilman, A. (1995). The assessment and interpretation of intellectual abilities in people with autism. In E. Schopler & G. B. Mesibov (Eds.), *Learning and cognition in autism* (pp.89-117). New York: Plenum.

Linn, M., & Petersen, A. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development, 56*, 1479-1498.

Liss, M., Fein, D., Allen, D., Dunn, M., Feinstein, C., Morris, R., Waterhouse, L., & Rapin, I. (2001). Executive functioning in high-functioning children with autism. *Journal of Child*

Psychology and Psychiatry, 42, 261-270.

Lockyer, L., & Rutter, M. (1970). A five to fifteen year follow-up study of infantile psychosis: IV. Patterns of cognitive ability. *British Journal of Social and Clinical Psychology, 9*, 152-163.

Lopez, B., & Leekam, S. R. (2003). Do children with autism fail to process information in context? *Journal of Child Psychology and Psychiatry, 44*, 285-300.

Lord, C., & Paul, R. (1997). Language and communication in autism. In D. Cohen & F. Volkmar (Eds.), *Handbook of autism and pervasive developmental disorders* (2nd ed., pp. 195-225). New York: John Wiley & Sons.

Lord, C., Risi, S., Lambrecht, L., Cook, E. H., Leventhall, B. L., DiLavore, P. C., Pickles, A., & Rutter, M. (2000). The Autism Diagnostic Observation Schedule-Generic: A standard measure of social and communication deficits associated with the spectrum of autism. *Journal of Autism and Developmental Disorders, 30*, 205-223.

Lord, C., Rutter, M., & LeCouteur, A. (1994). Autism Diagnostic Interview-Revised: A revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. *Journal of Autism and Developmental Disorders, 24*, 659-685.

Lovaas, O. I., Schreibman, L., Koegel, R., & Rehm, R. (1971). Selective responding by autistic children to multiple sensory input. *Journal of Abnormal Psychology, 77*, 211-222.

Loveland, K. A., Pearson, D. A., Tunali-Kotoski, B., Ortegon, J., & Gibbs, M. C. (2001). Judgements of social appropriateness by children and adolescents with autism. *Journal of Autism & Developmental Disorders, 31*, 367-376.

Lucci, D., Fein, D., Holevas, A., & Kaplan, E. (1988). Paul: A musically gifted autistic boy. In L. K. Obler & D. Fein (Eds.), *The exceptional brain: Neuropsychology of talent and special abilities* (pp. 310-324). New York: Guilford.

Luciana, M., Conklin, H. M., Hooper, C. J., & Yarger, R. S. (2005). The development of nonverbal working memory and executive control processes in adolescents. *Child Development, 76*, 697-712.

Luna, B., Garver, K. E., Urban, T. A., Lazar, N. A., & Sweeney, J. A. (2004). Maturation of cognitive processes from late childhood to adulthood. *Child Development, 75*, 1357-1372.

Lutchmaya, S., Baron-Cohen, S., & Raggatt, P. (2002a). Foetal testosterone and vocabulary size in 18- and 24-month-old infants. *Infant Behavior and Development, 24*, 418-424.

Lutchmaya, S., Baron-Cohen, S., & Raggett, P. (2002b). Foetal testosterone and eye contact in 12 month old infants. *Infant Behavior and Development, 25*, 327-335.

Ma, D. Q., Jaworski, J., Menold, M. M., Donnelly, S., Abramson, R. K., Wright, H. H., Delong, G. R., Gilbert, J. R., Pericak-Vance, M. A., & Cuccaro, M. L. (2005). Ordered-subset analysis of savant skills in autism for 15q11-q13. *American Journal of Medical Genetics, 135*, 38-41.

Maccoby, E. E., & Jacklin, C. N. (1974). *The psychology of sex differences.* Stanford, CA: Stanford University Press.

Manes, F., Piven, J., Vrancic, D., Nanclares, V., Plebst, C., & Starkstein, S. E. (1999). An MRI study of the corpus callosum and cerebellum in mentally retarded autistic individuals. *Journal of Neuropsychiatry & Clinical Neurosciences, 11*, 470-474.

Maybery, M., Taylor, M., & O'Brien-Malone, A. (1995). Implicit learning: Sensitive to age but not to IQ. *Australian Journal of Psychology, 47*, 8–17.

McDougle, C. J., Kresch, L. E., Goodman, W. K., Naylor, S. T., Volkmar, F. R., Cohen, D. J., & Price, L. H. (1995). A case-controlled study of repetitive thoughts and behavior in adults with autistic disorder and obsessive-compulsive disorder. *American Journal of Psychiatry, 152*, 772-777.

Mesibov, G. (1983). Current perspectives and issues in autism and adolescence. In E. Schopler & G. Mesibov (Eds.), *Autism in adolescents and adults* (pp. 37-53). New York: Plenum

Press.

Mesibov, G. B. (1984). Social skills training with verbal autistic adolescents and adults: A program model. *Journal of Autism and Developmental Disorders, 14*, 395-404.

Meulemans, T., van der Linden, M., & Perruchet, P. (1998). Implicit sequence learning in children. *Journal of Experimental Child Psychology, 69*, 199-221.

Miller, B. L., Cummings, J., Mishkin, F., Boone, K., Prince, F., Ponton, M., & Cotman, C. (1998). Emergence of artistic talent in frontotemporal dementia. *Neurology, 51*, 978-982.

Miller, B. L., Ponton, M., Benson, D. F., Cummings, J. L., & Mena, I. (1996). Enhanced artistic creativity with temporal lobe degeneration. *Lancet, 348*, 1744-1755

Miller, L. (1989). *Musical savants: Exceptional skill in the mentally retarded.* Hillsdale, NJ: Lawrence Erlbaum and Associates.

Miller, L. (1995). Sensitivity to sequential structure in musical savants. *American Journal Mental Retardation, 99*, 391-398.

Miller, L. (1998). Defining the savant syndrome. *Journal of Developmental and Physical Disabilities, 10*, 73-85.

Miller, L. J., & McIntosh, D. N. (1998). The diagnosis, treatment and etiology of sensory modulation disorder. American Occupational Therapy Association Sensory Integration Special Interest Section Quarterly, 21, 1-3.

Milne, E., Swettenham, J., Hansen, P., Campbell, R., Jeffries, H., & Plaisted, K. (2002). High motion coherence thresholds in children with autism. *Journal of Child Psychology and Psychiatry, 43*, 255-263.

Minshew, N., & Goldstein, G. (1993). Is autism an amnesic disorder? Evidence from the California Verbal Learning Test. Neuropsychology, 7, 209-216.

Minshew, N. J., & Goldstein, G. (2001). The pattern of intact and impaired memory functions in autism. *Journal of Child Psychology and Psychiatry, 42*, 1095-1101.

Minshew, N. J., Goldstein, G., & Siegel, D. J. (1997). Neuropsychologic functioning in autism: Profile of a complex information processing disorder. *Journal of the International Neuropsychological Society, 3*, 303-316.

Minshew, N. J., Turner, C. A., & Goldstein, G., (2005). The application of short forms of the Wechsler Intelligence scales in adults and children with high functioning autism. *Journal of Autism and Developmental Disorders, 35*, 45-52.

Moriarty, J., Ring, H. A., & Robertson, M. M. (1993). An idiot savant calendrical calculator with Gilles de la Tourette syndrome: Implications for an understanding of the savant syndrome. *Psychological Medicine, 23*, 1019-1021.

Morrell, T. L., Young, R. L., & Ridding, M. C. (2000). ***Investigation of latent savant skills using trancranial magnetic stimulation.*** Unpublished honours thesis, University of South Australia

Moses, P., Roe, K., Buxton, R. B., Wong, E. C., Frank, L. R., & Stiles, J. (2002). Functional MRI of global and local processing in children. *Neuroimage, 16*, 415-424.

Mostofsky, S. H., Goldberg, M. C., Landa, R. J., & Denckla, M. B. (2000). Evidence for a deficit in procedural learning in children and adolescents with autism: implications for cerebellar contribution. *Journal of International Neuropsychological Society, 6*, 752-759.

Mottron, L., & Belleville, S. (1993). A study of perceptual analysis in a high-level autistic subject with exceptional graphic abilities. ***Brain and Cognition, 23***, 279-309.

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

Mottron, L., Belleville, S., & Ménard, E. (1999). Local bias in autistic subjects as evidenced by graphic tasks: Perceptual hierarchization or working memory deficit? *Journal of Child Psychology and Psychiatry, 40*, 743-755.

Mottron, L., Belleville, S., & Stip, E. (1996). Proper name hypermnesia in an autistic subject.

Brain and Language, 53, 326-350.

Mottron, L., Belleville, S., Stip, E., & Morasse, K. (1998) Atypical memory performance in an autistic savant. *Memory, 6*, 593-607

Mottron, L., & Burack, J. A. (2001). Enhanced perceptual functioning in the development of autism. In J. A. Burack, T. Charman, N. Yirmiya, & P. R. Zelazo (Eds.), *The development of autism* (pp. 131-148). Mahwah, NJ: Lawrence Erlbaum Associates.

Mottron, L., Burack, J. A., Stauder, J. E. A., & Robaey, P. (1999). Perceptual processing among high-functioning persons with autism. *Journal of Child Psychology and Psychiatry, 40*, 203-211.

Mottron, L., Dawson, M., Soulieres, I., Hubert, B., & Burack, J. (2006). Enhanced perceptual functioning in autism: An update, and eight principles of autistic perception. *Journal of Autism and Developmental Disorders, 36*, 27-43.

Mottron, L., Morasse, K., & Belleville, S. (2001). A study of memory functioning in individuals with autism. *Journal of Child Psychology and Psychiatry and Allied Disciplines, 42*, 253-260.

Mottron, L., Peretz, I., Belleville, S., & Rouleau, N. (1999). Absolute pitch in autism: A case study. *Neurocase, 5*, 485-501.

Mottron, L., Peretz, I., & Ménard, E. (2000). Local and global processing of music in high-functioning persons with autism: Beyond central coherence? *Journal of Child Psychology and Psychiatry, 41*, 1057-1065.

Mundy, P. (1995). Joint attention and social-emotional approach behavior in children with autism. *Development and Psychopathology, 7*, 63-82.

Nation, K. (1999). Reading skills in hyperlexia: A developmental perspective. *Psychological Bulletin, 125*, 338-355.

Navon, D. (1977). Forest before the trees: The precedence of global features in visual perception. *Cognitive Psychology, 9*, 353-383.

Nelson, K. B. (1991). Prenatal and perinatal factors in the etiology of autism. *Pediatrics, 87*, 761-766.

Nelson, E. C., & Pribor, E. F. (1993). A calendar savant with autism and Tourette syndrome: Response to treatment and thoughts on the interrelationships of these conditions. *Annals of Clinical Psychiatry, 5*, 135-140.

Nettelbeck, T. (1987). Inspection time and intelligence. In P.A. Vernon (Ed.), *Speed of information processing and intelligence* (pp. 295-346). Norwood, NJ: Ablex.

Nettelbeck, T., & Young, R. (1996). Intelligence and savant syndrome: Is the whole greater than the sum of the fragments? *Intelligence, 22*, 49-67.

Nettelbeck, T., & Young, R. (1999). Savant syndrome. In C. M. Glidden (Ed.), *International Review of Research in Mental Retardation* (pp.137-173). New York: Academic Press.

Nissen, M. J., & Bullemer, P. (1987). Attentional requirements of learning: Evidence from performance measures. *Cognitive Psychology, 19*, 1–32.

Nurmi, E. L., Dowd, M., Tadevosyan-Leyfer, O., Haines, J. L., Folstein, S. E., & Sutcliffe, J. S. (2003). Explorary subsetting of autism families based on savant skills improves evidence of genetic linkage to 15q11-q13. *Journal of the American Academy of Child & Adolescent Psychiatry, 42*, 856-863.

Obler, L. K., & Fein, D. (1988). *The exceptional brain: Neuropsychology of talent and special abilities.* New York: Guilford.

O'Connor, N. (1989). The performance of the savant – Implicit and explicit. *British Journal of Disorders of Communication, 24*, 1-20.

O'Connor, N., Cowan, R., & Samella, K. (2000). Calendrical calculation and intelligence. *Intelligence, 28*, 31-48.

O'Connor, N., & Hermelin, B. (1965). Sensory dominance in autistic imbecile children and controls. *Archives of General Psychiatry, 12*, 99-103.

O'Connor, N., & Hermelin, B. (1984). Idiot savant calendrical calculators: Maths or memory? *Psychological Medicine, 14*, 801-806.

O'Connor, N., & Hermelin, B. (1987a). Visual memory and motor programmes: Their use by idiot-savant artists and controls. *British Journal of Psychology, 78*, 307-323.

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

O'Connor, N., & Hermelin, B. (1989). The memory structure of autistic idiot-savant mnemonists. *British Journal of Psychology, 80*, 97-111.

O'Connor, N., & Hermelin, B. (1990). The recognition failure and graphic success of idiot-savant artists. *Journal of Child Psychology and Psychiatry, 31*, 203-215.

O'Connor, N., & Hermelin, B. (1991). Talents and preoccupations in idiot-savants. *Psychological Medicine, 21*, 959-964.

O'Connor, N., Smith, N., Frith, C., & Tsimpli, I. (1994). Neuropsychology and linguistic talent. Journal of Neurolinguistics, 8, 95-107.

O'Neill, M., & Jones, R. S. P. (1997). Sensory-perceptual abnormalities in autism: A case for more research? *Journal of Autism and Developmental Disorders, 27*, 283-293.

O'Riordan, M., & Plaisted, K. (2001). Enhanced discrimination in autism. *Quarterly Journal of Experimental Psychology A: Human Experimental Psychology, 54*, 961-979.

O'Riordan, M. A., Plaisted, K. C., Driver, J., & Baron-Cohen, S. (2001). Superior visual search in autism. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 719-730.

Ornitz, E. M., & Ritvo, E. R. (1968). Perceptual inconstancy in early infantile autism. The syndrome of early infant autism and its variants including certain cases of childhood schizophrenia. *Archives of General Psychiatry, 18*, 76-98.

Osterling, J., & Dawson, G. (1994). Early recognition of children with autism: A study of first birthday home videotapes. *Journal of Autism and Developmental Disorders, 24*, 247-257.

Osterrieth, P. A. (1944). Le test de copie d'une figure complexe. *Archives de Psychologie, 30*, 206-356.

Ozonoff, S. (1995). Executive functions in autism. In E. Schopler & G. Mesibov (Eds.), *Learning and cognition in autism* (199-219). New York: Plenum Press.

Ozonoff, S., & Miller, J. N. (1996). An exploration of right-hemisphere contributions to the pragmatic impairments of autism. *Brain and Language, 52*, 411-434.

Ozonoff, S., Pennington, B. F., & Rogers, S. J. (1991). Executive function deficits in high-functioning autistic individuals: Relationship to theory of mind. *Journal of Child Psychology and Psychiatry, 32*, 1081-1105.

Ozonoff, S., & Strayer, D. L. (1997). Inhibitory function in nonretarded children with autism. *Journal of Autism and Developmental Disorders, 27*, 59-77.

Ozonoff, S., Strayer, D., McMahon, W., & Filloux, F. (1994). Executive function abilities in autism and Tourette syndrome: An information processing approach. *Journal of Child Psychology and Psychiatry, 35*, 1015-1032.

Palmen, S. J., van Engeland, H., Hof, P. R., & Schmitz, C. (2004). Neuropathological findings in autism. *Brain, 127*, 2572-2583.

Paul, R., Augustyn, A., Klin, A., & Volkmar, F. R. (2005). Perception and production of prosody by speakers with autism spectrum disorders. *Journal of Autism & Developmental Disorders, 35*, 205-220.

Pellicano, E., Gibson, L., Maybery, M., Durkin, K., & Badcock, D. R. (2005). Abnormal global processing along the dorsal visual pathway in autism: a possible mechanism for weak visuospatial coherence? *Neuropsychologia, 43*, 1044-1053.

Pennings, A. (1988). The development of strategies in embedded figures tasks. *International Journal of Psychology, 23*, 65-78.

Perruchet, P., & Vinter, A. (1998). Learning and development: The implicit knowledge assumption reconsidered. In M. A. Stadler & P. A. Frensch (Eds.), Handbook of implicit learning *(pp. 495-531). Thousand Oaks, CA: Sage Publications.*

Pesenti, M., Seron, X., Samson, D., & Duroux, B. (1999). Basic and exceptional calculation abilities in a calculating prodigy: A case study. *Mathematical Cognition, 5,* 97-148.

Pesenti, M., Zago, L., Crivello, F., Mellet, E., Samson, D., Duroux, B., Seron, X., Mazoyer, B., & Tzourio-Mazoyer, N. (2001). Mental calculation in a prodigy is sustained by right prefrontal and medial temporal areas. *Nature Neuroscience, 4,* 103-107.

Pfeiffer, S. I., Norton, J., Nelson, L., & Shott, S. (1995). Efficacy of vitamin B6 and magnesium in the treatment of autism: A methodology review and summary of outcomes. *Journal of Autism and Developmental Disorders, 25,* 481-93.

Phillips, W. A., Chapman, K. L., & Berry, P. D. (2004). Size perception is less context-sensitive in males. *Perception, 33,* 79-86.

Pierce, K., & Schreibman, L. (1995). Increasing complex social behaviors in children with autism: Effects of peer-implemented pivotal response training. *Journal of Applied Behavior Analysis, 28,* 285-295.

Piven, J., Arndt, S., Bailey, J., & Andreasen, N. (1996). Regional brain enlargement in autism: A magnetic resonance imaging study. *Journal of the American Academy of Child and Adolescent Psychiatry, 35,* 530-536.

Piven, J., Bailey, J., Ranson, B. J., & Arndt, S. (1998). No difference in hippocampus volume detected on magnetic resonance imaging in autistic individuals. *Journal of Autism and Developmental Disorders, 28,* 105-110.

Piven, J., Chase, G. A., Landa, R., Wzorek, M., Gayle, J., Cloud, D., & Folstein, S. (1991). Psychiatric disorders in the parents of autistic individuals. *Journal of the American Academy of Child and Adolescent Psychiatry, 30,* 471-478.

Piven, J., & Palmer, P. (1997). Cognitive deficits in parents from multiple incidence autism families. *Journal of Child Psychology and Psychiatry, 38,* 1011-1022.

Piven, J., Wzorek, M., Landa, R., Lainhart, J., Bolton, P., Chase, G. A., & Folstein, S. (1994). Personality characteristics of the parents of autistic individuals. *Psychological Medicine, 24,* 783-795.

Plaisted, K. C. (2001). Reduced generalization in autism: An alternative to weak central coherence. In J. A. Burack, T. Charman, N. Yirmiya, & P. R. Zelazo (Eds.), *The development of autism* (pp. 149-169). Mahwah, NJ: Lawrence Erlbaum Associates.

Plaisted, K. C., O'Riordan, M., & Baron-Cohen, S. (1998). Enhanced discrimination of novel, highly similar stimuli by adults with autism during a perceptual learning task. *Journal of Child Psychology and Psychiatry, 39,* 765-775.

Plaisted, K., Saksida, L.,Alcantara, J., & Weissblatt, E. (2003). Towards an understanding of the mechanisms of weak central coherence effects: Experiments in visual configural learning and auditory perception. *Philosophical Transactions of the Royal Society, 358,* 375-386.

Plaisted, K., Swettenham, J., & Rees, L. (1999). Children with autism show local precedence in a divided attention task and global precedence in a selective attention task. *Journal of Child Psychology and Psychiatry, 40,* 733-742.

Platel, H., Price, C., Baron, J. C., Wise, R., Lambert, J., Frackowiak, R. S., Lechevalier, B., & Eustache, F. (1997). The structural components of music perception. A functional anatomical study. *Brain, 120,* 229-243.

Poustka, F., & Lisch, S. (1993). Autistic behavior domains and their relation to self-injurious behavior. *Acta Paedopsychiatrica, 56,* 69-73.

Pring, L., & Hermelin, B. (1993). Bottle, tulip and wineglass: Semantic and structural picture processing by savant artists. *Journal of Child Psychology and Psychiatry, 34,* 1365-1385.

Pring, L., & Hermelin, B. (2002). Numbers and letters: exploring an autistic savant's unpracticed ability. *Neurocase, 8*, 330-337.

Pring, L., Hermelin, B., Buhler, M., & Walker, I. (1997). Native savant talent and acquired skill. *Autism, 1*, 199-214.

Pring, L., Hermelin, B., & Heavey, L. (1995). Savants, segments, art and autism. *Journal of Child Psychology and Psychiatry, 36*, 1065-1076.

Prior, M. R. (1979). Cognitive abilities and disabilities in infantile autism: a review. *Journal of Abnormal Child Psychology, 7*, 357-380.

Prior, M., & Hoffman, W. (1990). Brief report: Neuropsychological testing of autistic children through an exploration with frontal lobe tests. *Journal of Autism and Developmental Disorders, 20*, 581-590.

Prizant, B. M., Schuler, A. L., Wetherby, A. M., & Rydell, P. R. (1997). Enhancing language and communication: Language approaches. In D. Cohen & F. Volkmar (Eds.), *Handbook of autism and pervasive developmental disorders* (2nd ed., pp. 572-605). New York: John Wiley & Sons.

Rammsayer, T., & Lustnauer, S. (1989). Sex differences in time perception. *Perceptual and Motor Skills, 68*, 195-198.

Reber, A. S. (1993). *Implicit learning and tacit knowledge: An essay on the cognitive unconscious.* New York: Oxford University Press.

Reber, A. S., Walkenfeld, F. F., & Hernstadt, R. (1991). Implicit and explicit learning: Individual differences and IQ. *Journal of Experimental Psychology: Learning, Memory & Cognition, 17*, 888-896.

Renner, P., Klinger, L. G., & Klinger, M. (2000). Implicit and explicit memory in autism: Is autism an amnesic disorder? *Journal of Autism and Developmental Disorders, 30*, 3-14.

Rimland, B. (1964). *Infantile autism: The syndrome and its implications for neural theory of behavior.* New York: Appleton-Century-Crofts.

Rimland, B. (1978). Savant capabilities of autistic children and their cognitive implications. In G. Serban (Ed.), *Cognitive defects in the development of mental illness* (pp. 43-65). New York: Brunner-Mazel.

Rinehart, N. J., Bradshaw, J. L., Moss, S. A., Brereton, A. V., & Tonge, B. J. (2000). Atypical interference of local detail on global processing in high-functioning autism and Asperger's disorder. *Journal of Child Psychology and Psychiatry, 41*, 769-778.

Ring, H. A., Baron-Cohen, S., Wheelwright, S., Williams, S. C. R., Brammer, M., Andrew, C., & Bullmore, E. T. (1999). Cerebral correlates of preserved cognitive skills in autism: A functional MRI study of Embedded Figures Task performance. *Brain, 122*, 1305-1315.

Ritvo, E. R., Freeman, B. J., Scheibel, A. B., Duong, P. T., Robinson, H., Guthrie, D., & Ritvo, A. (1986). Lower Purkinje cell counts in the cerebella of four autistic subjects: Initial findings of the UCLA-NSAC autopsy research project. *American Journal of Psychiatry, 13*, 862-866.

Robinson, J. O., & Wilson, J. A. (1973). The impossible colonnade and other variations of a well-known figure. *British Journal of Psychology, 64*, 363-365.

Rodgers, J. (2000). Visual perception and Asperger syndrome: central coherence deficit or hierarchization deficit? *Autism, 4*, 321-329.

Rodier, P. M. (2002). Converging evidence for brain stem injury in autism. *Development and Psychopathology, 14*, 537-557.

Roeckelein, J. E. (1972). Sex differences in time estimation. *Perceptual and Motor Skills, 35*, 859-862.

Rogers, S. J. (1998). Empirically supported comprehensive treatments for young children with autism. *Journal of Clinical Child Psychology, 27*, 168-179.

Rogers, S. J., Hepburn, S., & Wehner, E. (2003). Parent reports of sensory symptoms in toddlers with autism and those with other developmental disorders. *Journal of Autism and Developmental Disorders, 33*, 631-642.

Rogers, S. J., & Ozonoff, S. (2005). Annotation: what do we know about sensory dysfunction in autism? A critical review of the empirical evidence. *Journal of Child Psychology and Psychiatry*. *46*, 1255-1268.

Ronald, A., Happé, F., & Plomin, R. (2005). The genetic relationship between individual differences in social and nonsocial behaviours characteristic of autism. *Developmental Science, 8*, 444-458.

Ropar, D., & Mitchell, P. (1999). Are individuals with autism and Asperger's syndrome susceptible to visual illusions? *Journal of Child Psychology and Psychiatry, 40*, 1283-1293.

Ropar, D., & Mitchell, P. (2001). Susceptibility to illusions and performance on visuospatial tasks in individuals with autism. Journal of Child Psychology and Psychiatry, 42, *539-549.*

Ropar, D., & Mitchell, P. (2002). Shape constancy in autism: the role of prior knowledge and perspective cues. *Journal of Child Psychology and Psychiatry, 43*, 647-653.

Rosenhall, U., Nordin, V., Sandstrom, M., Ahlsen, G., & Gillberg, C. (1999). Autism and hearing loss. *Journal of Autism and Developmental Disorders, 29*, 349-357.

Rubia, K., & Smith, A. (2004). The neural correlates of cognitive time management: a review. *Acta Neurobiologiae Experimentalis, 64*, 329-340.

Rubin, E. J., & Monaghan, S. (1965). Calendar calculation in a multiple-handicapped blind person. *American Journal of Mental Deficiency, 70*, 478-485.

Rugg, M. D., Mark, R. E., Wala, P., Schloerscheidt, A. M., Birch, C. S., & Allan, K. (1998). Dissociation of the neural correlates of implicit and explicit memory. *Nature, 392*, 595-598.

Rumsey, J. M. (1985). Conceptual problem-solving in highly verbal, nonretarded autistic men. *Journal of Autism and Developmental Disorders, 15*, 23-26.

Rumsey, J. M. (1992). Neuropsychological studies of high-level autism. In E. Schopler & G. Mesibov (Eds.), *High-functioning individuals with autism* (pp. 41-64). New York: Plenum.

Rumsey, J. M., & Hamburger, S. D. (1988). Neuropsychological findings in high-functioning men with infantile autism, residual state. *Journal of Clinical & Experimental Neuropsychology, 10*, 201-221.

Rumsey, J. M., & Hamburger, S. D. (1990). Neuropsychological divergence of high-level autism and severe dyslexia. *Journal of Autism and Developmental Disorders, 20*, 155-168.

Rumsey, J. M., Mannheim, G., Aquino, T., Gordon, C. T., & Hibbs, E. (1992). Neuropsychological characteristics of calendar calculating savants with pervasive developmental disorders. *Clinical Neuropsychologist, 6*, 320.

Runco, M. A., Charlop, M. H., & Schreibman, L. (1986). The occurrence of autistic children's self-stimulation as a function of familiar versus unfamiliar stimulus conditions. *Journal of Autism and Developmental Disorders, 16*, 31-34.

Russell, J. (Ed). (1997). *Autism as an executive disorder*. New York: Oxford University Press.

Rutter, M. (2000). Genetic studies of autism: From the 1970s into the Millenium. *Journal of Abnormal Child Psychology, 28*, 3-14.

Rutter, M., Andersen-Wood, L., Beckett, C., Brendenkamp, D., Castle, J., Groothues, C., Kreppner, J., Keaveney, L., Lord, C., O'Connor, T. G., & the English and Romanian Adoptees Study Team. (1999). Quasi-autistic patterns following severe early global privation. *Journal of Child Psychology and Psychiatry, 40*, 537-549.

Rutter, M., Bailey, A., Bolton, P., & LeCouteur, A. (1994). Autism and known medical conditions: Myth and substance. *Journal of Child Psychology and Psychiatry, 35*, 311-322.

Rutter, M., Bailey, A., Simonoff, E., & Pickles, A. (1997). Genetic influences and autism. In D.

J. Cohen & F. R. Volkmar (Eds.), *Handbook of autism and pervasive developmental disorders* (2nd ed., pp. 370-387). New York: John Wiley & Sons.

Ryder, N., Pring, L., & Hermelin, B. (2002). Lack of coherence and divergent thinking: Two sides of the same coin in artistic talent? *Current Psychology, 21*, 168-175.

Sacks, O. (1985, February 28). The twins. *The New York Review of Books*, 32, 16-20.

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

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science, 274*, 1926-1928.

Saitoh, O., Karns, C. M., & Courchesne, E. (2001). Development of the hippocampal formation from 2 to 42 years: MRI evidence of smaller area dentata in autism. *Brain, 124*, 1317-1324.

Saloviita, T., Ruusila, U., & Ruusila, L. (2000). Incidence of savant syndrome in Finland. *Perceptual and Motor Skills, 91*, 120-122.

Sandler, A. D., Sutton, K. A., DeWeese, J., Girardi, M. A., Sheppard, V., & Bodfish, J. W. (1999). Lack of benefit of a single dose of synthetic human secretin in the treatment of autism and pervasive developmental disorder. *New England Journal of Medicine, 341*, 1801-1806.

Sano, F. (1918). James Henry Pullen, the genius of Earlswood. *Journal of Mental Science, 64*, 251-267.

Sattler, J. M. (1992). *Assessment of Children 3rd Edition*. San Diego: Jerome M. Sattler, Publisher, Inc.

Schacter, D. L., Chiu, C. Y. P., & Ochsner, K. N. (1993). Implicit memory: A selective review. *Annual Review of Neuroscience, 16*, 159-182.

Scheuffgen, K. (1998). *Domain-general and domain-specific deficits in autism and dyslexia*. Unpublished PhD thesis, University of London.

Scheuffgen, K., Happé, F., Anderson, M., & Frith, U. (2000). High "intelligence", low "IQ"? Speed of processing and measured IQ in children with autism. *Development and Psychopathology, 12*, 83-90.

Schopler, E. (1965). Early infantile autism and receptor processes. *Archives of General Psychiatry, 13*, 327-335.

Schopler, E., Mesibov, G. B., & Hearsey, K. (1995). Structured teaching in the TEACCH system. In E. Schopler & G. B. Mesibov (Eds.), *Learning and cognition in autism* (pp. 243-268). New York: Plenum Press.

Schultz, R. T., Gauthier, I., Klin, A., Fulbright, R. K., Anderson, A. W., Volkmar, F., Skudlarski, P., Lacadie, C., Cohen, D. J., & Gore, J. C. (2000). Abnormal ventral temporal cortical activity during face discrimination among individuals with autism and Asperger syndrome. *Archives of General Psychiatry, 57*, 331-340.

Seger, C. A. (1994). Implicit learning. *Psychological Bulletin, 115*, 163-196.

Selfe, L. (1978). *Nadia: A case of extraordinary drawing ability in an autistic child*. London: Academic Press.

Selfe, L. (1995). Nadia reconsidered. In C. Golomb (Ed.), *The development of artistically gifted children* (pp. 197-237). Hillsdale, NJ: Erlbaum.

Sergeant, J. A., Geurts, H., & Oosterlaan, J. (2002). How specific is a deficit of executive functioning for attention-deficit/hyperactivity disorder? *Behavioural Brain Research, 130*, 3-28.

Shah, A., & Frith, U. (1983). An islet of ability in autistic children: A research note. *Journal of Child Psychology and Psychiatry, 24*, 613-620.

Shah, A., & Frith, U. (1993). Why do autistic individuals show superior performance on the Block Design test? *Journal of Child Psychology and Psychiatry, 34*, 1351-1364.

Shanks, D. R., & St. John, M. F. (1994). Characteristics of dissociable learning systems. *Behavioral and Brain Sciences, 17*, 367-395.

Shinkfield, A. J., Sparrow, W. A., & Day, R. H. (1997). Visual discrimination and motor reproduction of movement by individuals with mental retardation. *American Journal on Mental Retardation, 102*, 172-181.

Sigman, M., Mundy, P., Sherman, T., & Ungerer, J. (1986). Social interactions of autistic, mentally retarded and normal children and their caregivers. *Journal of Child Psychology and Psychiatry, 27*, 647-656.

Sigman, M., & Ungerer, J. (1981). Sensorimotor skills and language comprehension in autistic children. *Journal of Abnormal Child Psychology, 9*, 149-165.

Simonton, D. K. (2001). Talent development as a multidimensional, multiplicative, and dynamic process. *Current Directions in Psychological Science, 10*, 39-43.

Skuse, D. H., James, R. S., Bishop, D. V., Coppin, B., Dalton, P., Aamodt-Leeper, G., Bacarese-Hamilton, M., Creswell, C., McGurk, R., & Jacobs, P. A. (1997). Evidence from Turner's syndrome of an imprinted X-linked locus affecting cognitive function. *Nature, 387*, 705-708.

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

Smith, S. B. (1983). *The great mental calculators.* New York: Columbia University Press.

Smith, A., Taylor, E., Rogers, J. W., Newman, S., & Rubia, K. (2002). Evidence for a pure time perception deficit in children with ADHD. *Journal of Child Psychology and Psychiatry, 43*, 529-542.

Smith, N., & Tsimpli, I. (1995). *The mind of a savant: Language, learning and modularity.* Oxford: Blackwell.

Snowling, M., & Frith, U. (1986). Comprehension in 'hyperlexic' readers. *Journal of Experimental Child Psychology, 42*, 392-415.

Snyder, A. W., & Mitchell, D. J. (1999). Is integer arithmetic fundamental to mental processing?: The mind's secret arithmetic. *Proceedings of the Royal Society of London, 266*, 587-592.

Snyder, A. W., Mulcahy, E., Taylor, J. L., Mitchell, D. J., Sachdev, P., & Gandevia, S. C. (2003). Savant-like skills exposed in normal people by suppressing the left fronto-temporal lobe. *Journal of Integrative Neuroscience, 2*, 149-158.

Sonuga-Barke, E. J., Saxton, T., & Hall, M. (1998). The role of interval underestimation in hyperactive children's failure to suppress responses over time. *Behavioral Brain Research, 94*, 45-50.

Sonuga-Barke, E. J., Williams, E., Hall, M., & Saxton, T. (1996). Hyperactivity and delay aversion III: The effect on cognitive style of imposing delay after errors. *Journal of Child Psychology and Psychiatry, 37*, 189-194.

Southall, G. (1979). *Blind Tom: The Post-Civil War enslavement of a black musical genius.* Minneapolis, MN: Challenge Productions.

Southall, G. (1983). *The continuing enslavement of Blind Tom, the pianist composer* (1868-1887). Minneapolis, MN: Challenge Productions.

Spearman, C. (1927). *The abilities of man.* London: Macmillan.

Spencer, J., O'Brien, J., Riggs, K., Braddick, O., Atkinson, J., & Wattam-Bell, J. (2000). Motion processing in autism: evidence for a dorsal stream deficiency. *Neuroreport, 21*, 2765-2767.

Spitz, H. H. (1995). Calendar calculating idiots savants and the smart unconscious. *New Ideas in Psychology, 13*, 167-182.

Spitz, H. H., & LaFontaine, L. (1973). The digit span of idiots savants. *American Journal of Mental Deficiency, 77*, 757-759.

Steel, J. G., Gorman, R., & Flexman, J. E. (1984). Neuropsychiatric testing in an autistic mathematical idiot-savant: Evidence for nonverbal abstract capacity. *Journal of the American Academy of Child Psychiatry, 23,* 704-707.

Stevens, D., & Moffitt, T. (1988). Neuropsychological profile of an Asperger's syndrome case with exceptional calculating ability. *Clinical Neuropsychologist, 2,* 228-238.

Stoodley, C. J., Harrison, E. P., & Stein, J. F. (2006). Implicit motor learning deficits in dyslexic adults. *Neuropsychologia, 44,* 795-798.

Stromland, K., Nordin, V., Miller, M., Akerstrom, B., & Gillberg, C. (1994). Autism in thalidomide embryopathy: a population study. *Developmental Medicine and Child Neurology, 36,* 351-356.

Szelag, E., Kowalska, J., Galkowski, T., & Poppel, E. (2004). Temporal processing deficits in high-functioning children with autism. *British Journal of Psychology, 95,* 269-282.

Tager-Flusberg, H. (1991). Semantic processing in the free recall of autistic children: Further evidence for a cognitive deficit. *British Journal of Developmental Psychology, 9,* 417-430.

Takeuchi, A. H., & Hulse, S. H. (1993). Absolute pitch. *Psychological Bulletin, 113,* 345-361.

Tantam, D., Monaghan, L., Nicholson, H., & Stirling, J. (1989). Autistic children's ability to interpret faces: a research note. *Journal of Child Psychology and Psychiatry, 30,* 623-630.

Taylor, M. M., & Creelman, C. D. (1967). PEST: efficient estimates on probability functions. *The Journal of the Acoustical Society of America, 41,* 782-787.

Taylor, B., Miller, E., Farrington, C. P., Petropoulos, M. C., Favot-Mayaud, I., Li, J., & Waight, P. A. (1999). Autism and measles, mumps, and rubella vaccine: No epidemiological evidence for a causal association. *Lancet, 353,* 2026-2029.

Tecchio, F., Benassi, F., Zappasodi, F., Gialloreti, L. E., Palermo, M., Seri, S., & Rossini, P. M. (2003). Auditory sensory processing in autism: a magnetoencephalographic study. *Biological Psychiatry, 15,* 647-654.

Temple, C. M., & Carney, R. (1996). Reading skills in children with Turner's syndrome: An analysis of hyperlexia. *Cortex, 32,* 335-345.

Térouanne, E. (1980). On a class of impossible figures – A new language for a new analysis. *Journal of Mathematical Psychology, 22,* 24-47.

Teunisse, J., Cools, A. R., van Spaendonck, K. P. M., Aerts, F. H. T. M., & Berger, H. J. C. (2001) Cognitive styles in high-functioning adolescents with autistic disorder. *Journal of Autism and Developmental Disorders, 31,* 55-66.

Thomas, K. M., Hunt, R. H., Vizueta, N., Sommer, T., Durston, S., Yang, Y., & Worden, M. S. (2004). Evidence of developmental differences in implicit sequence learning: an fMRI study of children and adults. *Journal of Cognitive Neuroscience, 16,* 1339-1351.

Thomas, K. M., & Nelson, C. A. (2001). Serial reaction time learning in preschool- and school-age children. *Journal of Experimental Child Psychology, 79,* 364-387.

Toichi, M. & Kamio, Y. (2001). Verbal association for simple words in high-functioning autism. *Journal of Autism and Developmental Disorders, 5,* 483-490.

Toichi, M. & Kamio, Y. (2002). Long-term memory and levels-of-processing in autism. *Neuropsychologia, 40,* 964-969.

Tredgold, A. (1914). *Mental deficiency.* Baltimore: Williams & Wilkins.

Treffert, D. A. (1988). The idiot savant: A review of the syndrome. *American Journal of Psychiatry, 145,* 563-572.

Treffert, D. (1989). *Extraordinary people: Understanding "idiot savants."* New York: Harper & Row.

Treffert, D. A., & Wallace, G. L. (2002). Islands of Genius. *Scientific American,* 76-85.

Turner, M. A. (1999). Generating novel ideas: Fluency performance in high-functioning and learning disabled individuals with autism. *Journal of Child Psychology and Psychiatry, 40,* 189-201.

Valentine, E. R., & Wilding, J. M. (1994). Memory expertise. *The Psychologist, 7,* 405-408.

van Engeland, H., Bodnar, F. A., & Bolhuis, G. (1985). Some qualitative aspects of the social behaviour of autistic children: An ethological approach. *Journal of Child Psychology and Psychiatry, 26*, 879-893.

van Karnebeek, C. D., van Gelderen, I., Nijhof, G. J., Abeling, N. G., Vreken, P., Redeker, E. J., van Eeghen, A. M., Hoovers, J. M., & Hennekam, R. C. (2002). An aetiological study of 25 mentally retarded adults with autism. *Journal of Medical Genetics, 39*, 205-13.

Vicari, S., Bellucci, S., & Carlesimo, G. A. (2000). Implicit and explicit memory: a functional dissociation in persons with Down syndrome. *Neuropsychologia, 38*, 240-251.

Vinter, A., & Perruchet, P. (2000). Implicit learning in children is not related to age: evidence from drawing behavior. *Child Development, 71*, 1223-1240.

Vinter, A., & Perruchet, P. (2002). Implicit motor learning through observational training in adults and children. *Memory and Cognition, 30*, 256-261.

Vinter, A., & Detable, C. (2003). Implicit learning in children and adolescents with mental retardation. *American Journal on Mental Retardation, 108*, 94-107.

Volkmar, F. R., & Lord, C. (1998). Diagnosis and definition of autism and other pervasive developmental disorders. In F. R. Volkmar (Ed.), *Autism and pervasive developmental disorders* (pp. 1-31). Cambridge, UK: Cambridge University Press.

Volkmar, F. R., Lord, C., Bailey, A., Schultz, R. T., & Klin, A. (2004). Autism and pervasive developmental disorders. *Journal of Child Psychology & Psychiatry, 45*, 135-170.

Volkmar, F. R., & Nelson, D. S. (1990). Seizure disorders in autism. *Journal of the American Academy of Child and Adolescent Psychiatry, 1*, 127-129.

Volkmar, F. R., Sparrow, S. S., Goudreau, D., Cicchetti, D. V., Paul, R., & Cohen, D. J. (1987). Social deficits in autism: an operational approach using the Vineland Adaptive Behavior Scales. *Journal of the American Academy of Child & Adolescent Psychiatry, 26*, 156-161.

Voyer, D., Voyer, S., & Bryden, M. P. (1995). Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables. *Psychological Bulletin, 117*, 250-270.

Waiter, G. D., Williams, J. H., Murray, A. D., Gilchrist, A., Perrett, D. I., & Whiten, A. (2005). Structural white matter deficits in high-functioning individuals with autistic spectrum disorder: a voxel-based investigation. *Neuroimage, 24*, 455-461.

Waterhouse, L. (1988). Speculations on the neuroanatomical substrate of special talents. In L. K. Obler & D. Fein (Eds.), *The exceptional brain: Neuropsychology of talent and special abilities* (pp. 493-512). New York: Guilford.

Waterhouse, L., Fein, D., & Modahl, C. (1996). Neurofunctional mechanisms in autism. Psychological Review, 103, 457-489.

Welsh, M. C., Pennington, B. F., & Groisser, D. B. (1991). A normative-developmental study of executive function: A window on prefrontal function in children. *Developmental Neuropsychology, 7*, 131-149.

Welsh, M. C., Pennington, B. F., & Rogers, S. (1987). Word recognition and comprehension skills in hyperlexic children. *Brain and Language, 32*, 76-96.

West, J., Douglas, G., Houghton, S., Lawrence, V., Whiting, K., & Glasgow, K. (2000). Time perception in boys with attention-deficit/hyperactivity disorder according to time duration, distraction and mode of presentation. *Child Neuropsychology, 6*, 241-250.

Williams, G., King, J., Cunningham, M., Stephan, M., Kerr, B., & Hersh, J. H. (2001). Fetal valproate syndrome and autism: Additional evidence of an association. *Developmental Medicine and Child Neurology, 43*, 202-206.

Willingham, D. B., Salidis, J., & Gabrieli, J. D. (2002). Direct comparison of neural systems mediating conscious and unconscious skill learning. *Journal of Neurophysiology, 88*, 1451-1460.

Wilmer, J. B., Richardson, A. J., Chen, Y., & Stein, J. F. (2004). Two visual motion processing deficits in developmental dyslexia associated with different reading skills deficits. *Journal of Cognitive Neuroscience, 16*, 528-540.

Wimmer, H., & Perner, J. (1983). Beliefs about beliefs: representation and constraining function of wrong beliefs in young children's understanding of deception. *Cognition, 13*, 103-128.

Windham, G. C., Zhang, L., Gunier, R., Croen, L. A., & Grether, J. K. (2006). Autism spectrum disorders in relation to distribution of hazardous air pollutants in the San Francisco Bay Area. *Environmental Health Perspectives, 114*, 1-41.

Wing, L. (1981). Aspergers syndrome – A clinical account. *Psychological Medicine, 11*, 115-129.

Wing, L. (1993). The definition and prevalence of autism: A review. *European Child and Adolescent Psychiatry, 2*, 61-74.

Wing, L., & Gould, J. (1979). Severe impairments of social interaction and associated abnormalities in children: Epidemiology and classification. *Journal of Autism and Developmental Disorders, 9*, 11-29.

Witkin, H. A., Goodenough, D.R., & Karp, S. A. (1967). Stability of cognitive style from childhood to young adult. *Journal of Personality and Social Psychology, 7*, 291-300.

Witkin, H. A., Oltman, P. K., Raskin, E., & Karp, S. A. (1971). *A manual for the Embedded Figures Test.* Consulting Psychologists Press.

Young, A. W., & Deregowski, J. B. (1981). Learning to see the impossible. *Perception, 10*, 91-105.

Young, R. (1995). *Savant syndrome: Processes underlying extraordinary abilities.* Unpublished PhD thesis, University of Adelaide, South Australia.

Young, R., & Nettelbeck, T. (1994). The "intelligence" of calendrical calculators. *American Journal on Mental Retardation, 99*, 186-200.

Young, R., & Nettelbeck, T. (1995). The abilities of a musical savant and his family. *Journal of Autism and Developmental Disorders, 25*, 229-245.

Young, R. L., Ridding, M. C., & Morrell, T. L. (2004). Switching skills on by turning off part of the brain. *Neurocase, 10*, 215-222.

Zakay, D. (1992). The role of attention in children's time perception. *Journal of Experimental Child Psychology, 54*, 355-371.

Zakay, D., & Block, R. A. (1996). The role of attention in time estimation processes. In M. A. Pastor (Ed.), *Time, internal clocks, and movement* (pp. 143-164). Amsterdam, NL: Elsevier.

Zatorre, R. J. (2003). Absolute pitch: a model for understanding the influence of genes and development on neural and cognitive function. *Nature Neuroscience, 6*, 692-695.

Appendix A. Subtest Scores and Full Scale IQ Estimates for the ASD and Matched Control Participants.

Participant	FSIQ Estimate		Vocabulary		Block Design	
	ASD	MC	ASD	MC	ASD	MC
1	85	94	8	10	7	8
2	69	69	3	6	6	3
3	60	72	5	4	1	6
4	60	52	5	1	1	2
5	60	52	5	2	1	1
6	85	94	7	8	8	10
7	72	66	5	4	5	4
8	91	94	9	6	8	12
9	52	55	1	2	2	2
10	103	106	10	15	11	7
11	117	106	11	11	15	11
12	115	112	12	15	13	9
13	91	97	7	8	10	11
14	83	103	6	10	8	11
15	72	91	6	9	4	8
16	91	100	10	12	7	8
17	117	106	15	13	11	9
18	106	97	11	10	11	9
19	126	115	15	14	14	11
20	103	109	14	13	7	10
21	117	115	15	14	11	11
22	85	83	4	8	11	6
23	126	126	13	13	16	16
24	88	103	11	11	5	10
25	103	106	12	11	9	11
26	112	106	14	13	10	9
27	83	97	6	10	8	9
28	138	135	17	16	16	16

Appendix B. The Sentence Completion Task Items.

I was given a pen and ... *

The sea tastes of salt and ...

Hens lay eggs and ...

The woman took the cup and ... *

You can get burnt by the sun and ...

You can feed a child bread and ... *

Little boys grow up to be men and ...

In the sea there are fish and ...

In a cave lived a bat and ...

You can go hunting with a knife and ...

You can swallow apple ... *

The old shoe-maker mended the shoes and ...

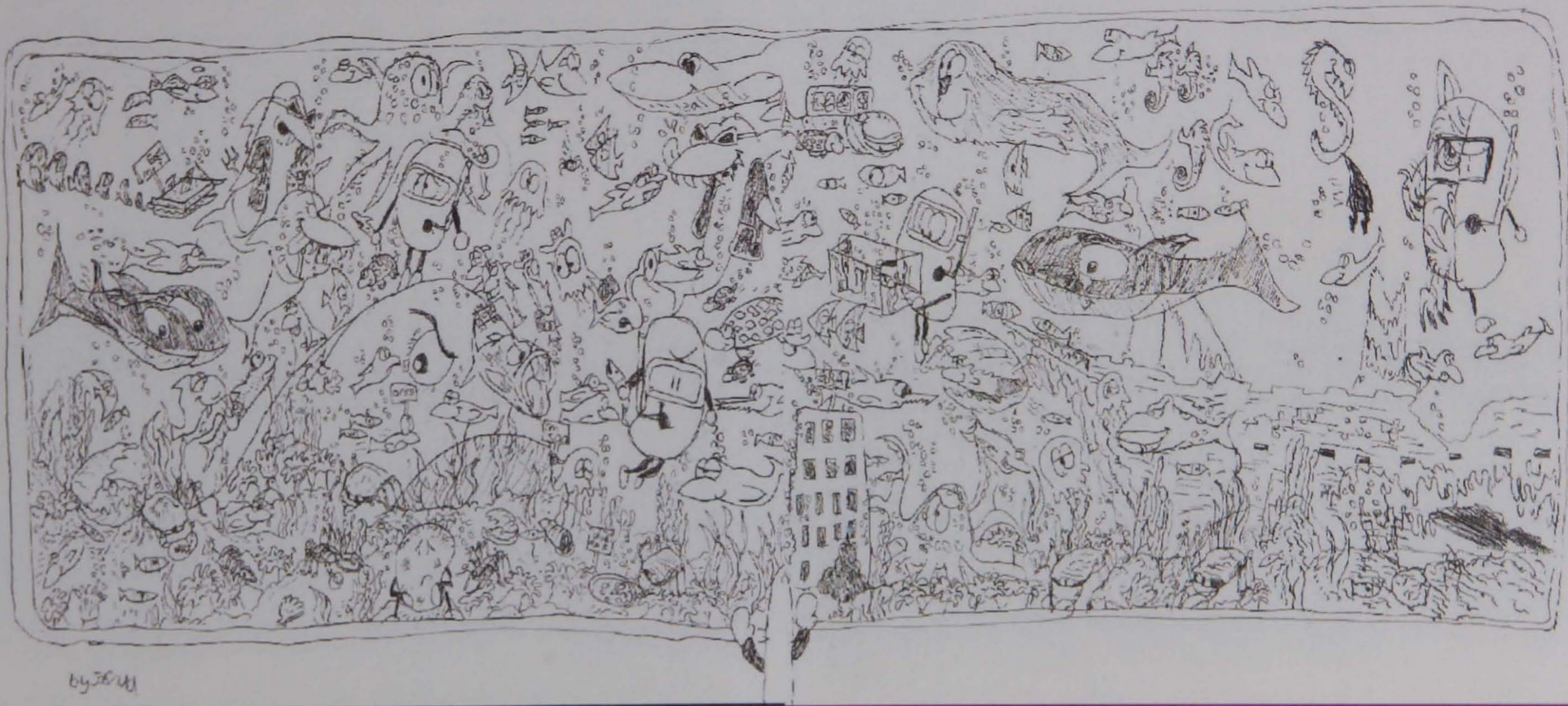
The fireman carried the bucket and ...

A vet cares for cats and ... *

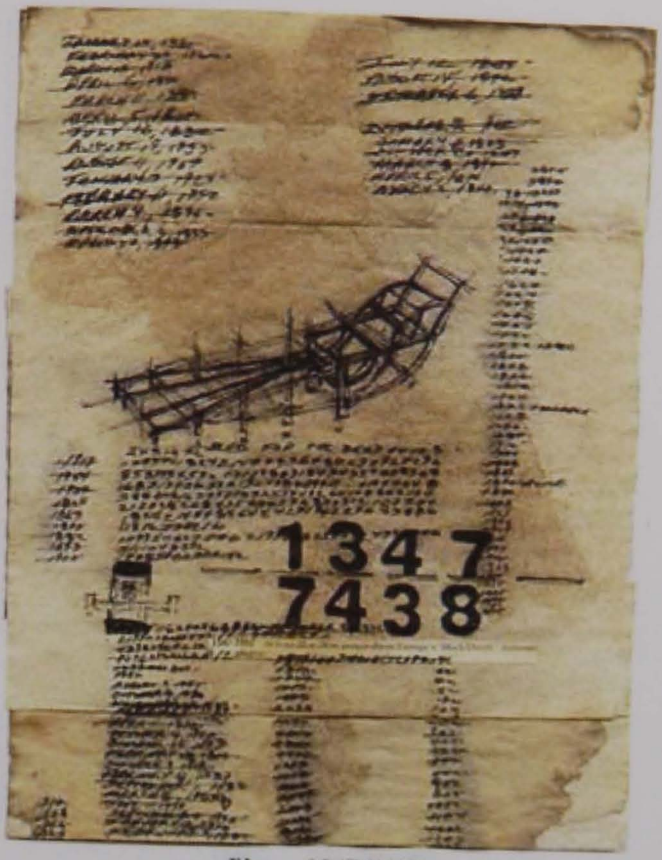
The night was black and ...

* - Control Items

Appendix C. An Example of Artwork by VT.



Appendix D. Two Examples of Artwork by MG.



Plague 1347-7438