

2010

Conditional reasoning in autism spectrum disorder: activation and integration of knowledge and belief.

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<http://hdl.handle.net/10026.1/304>

<http://dx.doi.org/10.24382/4700>

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CONDITIONAL REASONING IN AUTISM
SPECTRUM DISORDER: ACTIVATION AND
INTEGRATION OF KNOWLEDGE AND BELIEF

REBECCA KATE MCKENZIE

2016

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Conditional reasoning in autism spectrum disorder:
activation and integration of knowledge and belief.

Rebecca Kate McKenzie



Doctor of Philosophy

School of Psychology

2009

Abstract

Reasoning from all knowledge and belief is an adaptive approach to thinking about the world. It has been robustly shown that conditional 'if then' reasoning with everyday content is influenced by the background knowledge an individual has available. If we are presented with the statement *'if it rains, then John will get wet'* then we are told that it is raining and asked if John will get wet, we may consider a number of possibilities before answering the question; perhaps John has an umbrella or is sheltered from the rain. Hence, when engaged in conditional reasoning of this sort people typically draw on background knowledge to arrive at an informed response.

People with autism tend not to process information in context. There is a wealth of evidence indicating that these individuals have a piecemeal rather than an integrative processing style. It was therefore hypothesised that adolescents with autism spectrum disorder (ASD) would be less influenced by background knowledge when engaged in conditional reasoning with everyday content.

Adolescents with ASD showed a weak or absent effect of available background knowledge on reasoning outcomes compared to a typically developing control group. This finding was demonstrated in two separate conditional reasoning tasks. These results were not explained by a failure to generate background knowledge or by differences in the beliefs held by the two groups regarding problem content. Within the typical population a lack of contextualised reasoning was also found among participants with high scores on one particular autistic trait, attention to detail. The ability to integrate all relevant information during conditional reasoning was also found to be dependent on available working memory resources.

These results extend the known domains which demonstrate a lack of contextualised processing in autism. They also show that for individuals with autism reasoning without

regard for background knowledge stems from a failure to integrate information. The findings suggest that this failure is related to the cognitive demands of the task and the processing style of the individual.

Acknowledgments

I would like to thank Professor Jonathan Evans for providing the opportunity to study for a PhD and for his support, expert guidance and interest in my work. I would like to thank Professor Simon Handley for his help in my early research career and for his insight, advice and encouragement throughout my PhD. I would also like to thank the pupils and staff of Ridgeway School, Plymstock School, Tamarside Community College, Tavistock College, Callington Community College, Chelham Senior School and Launceston College.

Declaration

I declare that this thesis was composed by myself. The individual differences measures used to match participants in Experiments 1-4 were administered in collaboration with Kinga Morsanyi, a PhD student at The University of Plymouth. All other data was collected solely by myself. The conceptual design and analysis of the studies contained herein is my own, and this work has not been submitted for any other degree or professional qualification. Data from this thesis is included in two papers for publication. The first paper is currently in press in *Developmental Psychology* and the second under submission with *Psychonomic Bulletin and Review*.



(Rebecca Kate McKenzie)

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Chapter 1

Introduction

The studies presented in this thesis explore thinking and reasoning among individuals with autism spectrum disorder (ASD). This work brings together two extensive literatures. Studies relating to information processing abilities and styles in ASD, which demonstrate tendencies for decontextualised problem solving across a number of domains, and studies from the reasoning literature, specifically exploring everyday contextualised reasoning and the nature of the influence of knowledge and belief on conditional reasoning. Participants recruited for experiments include adolescents with high functioning autism or Asperger syndrome and typically developing adolescents and adults.

In this chapter I will outline major theories relating to autism including those relating to Theory of Mind and executive dysfunction. I will focus on other accounts which propose a tendency in ASD not to contextualise, or integrate information in order to arrive at higher meaning. This will include discussion of Weak Central Coherence Theory, Underconnectivity Theory, and the complex processing deficit account of autism. I will discuss evidence for a lack of contextualised thinking in studies of text comprehension. I will also examine possible preferences for visual as opposed to verbal thinking styles, and how this may relate to the integration of information in individuals with ASD.

Autism is a developmental disorder characterized predominantly by a triad of impairments in social interaction, communication and behavioural flexibility (World Health Organization, 1993). 10% of the autistic population also displays some form of savant skills or islet of special ability. These islets of ability may be in a number of given areas including intellectual, musical, artistic and visual. The symptoms falling under the social interaction category include impairment in the use of multiple nonverbal behaviours; failure to develop peer relationships; lack of spontaneous seeking to share interests and achievements with others, and a lack of social or emotional reciprocity. The symptoms falling under the communication category

include delay in or lack of spoken language development (with no compensation through other modes of communication). In individuals who do have speech, symptoms include a marked impairment in conversational skills, stereotyped and repetitive use of language, and lack of spontaneous age-appropriate social or imaginative play. The symptoms falling under the behavioural flexibility category include a preoccupation with stereotyped and restricted patterns of interest to an abnormal degree; inflexible adherence to non-functional routines or rituals; stereotyped and repetitive motor movements and a preoccupation with parts of objects (American Psychiatric Association, 1994).

The Diagnostic and Statistical Manual of Mental disorders (APA, 1994) defines Asperger syndrome as a separate disorder from autism. There is recognition, however, that those who are now diagnosed as having Asperger syndrome would previously have been labeled as having high functioning autism. Definitions of distinction between the two conditions differ but it is generally accepted that Asperger syndrome shares the social and behavioural symptoms of autism but development of spoken language follows a typical pattern. Since autism has been presented as a continuous spectrum there is some controversy as to whether Asperger syndrome should be diagnosed as a distinct disorder (See Matson & Boisjoli, 2008 for a review). For the purposes of our studies we consider Asperger syndrome to fall within the autistic spectrum and to be comparable to high functioning autism. This choice was made predominantly because some of the older participants had early diagnoses of high functioning autism, if they were diagnosed now, however, they may be diagnosed as having Asperger syndrome. As a result of these diagnostic changes those with an early diagnosis of high functioning autism and those with a more recent diagnosis of Asperger syndrome presented similar symptom profiles, especially in terms of language abilities. Whether Asperger syndrome and autism are distinct or not, there is a general consensus that widely used diagnostic measures such as DSM-IV and ICD-10 do not clearly outline differences or

provide sufficient detail to make reliable and valid distinctions between the two disorders at the present time (Matson & Wilkins, 2008).

A series of studies will be presented in this thesis exploring contextualised reasoning in individuals with ASD. Many current theories of autism focus on the tendency for individuals with ASD not to process information in context and to exhibit a piecemeal rather than an integrative processing style (e.g. Frith, 1989; Happé & Frith, 2006; Mottron & Burack, 2001; O’Riordan, Plaisted, Driver & Baron-Cohen, 2001). This tendency has been demonstrated by multiple tasks across a number of domains including visual and auditory perception, the processing of facial features and aspects of text comprehension such as homograph reading.

Most information processing accounts of autism acknowledge both enhanced local processing and reduced integration of information in ASD but differ in the centrality which they afford local or global processing. Studies of global processing in particular have presented some conflicting and complex findings, and some accounts claim that individuals with ASD are able to see the bigger picture in some cases, reflecting a tendency not to draw information together rather than an inability to do so (e.g. Happé & Frith, 2006). Other accounts claim that people with ASD are fundamentally impaired in their ability to integrate information (e.g. Just, Cherkassky, Keller & Minshew, 2004). There are also differences in the degree to which information processing style is thought to explain the symptoms associated with autism, although all accounts accept that processing implications are not domain specific and have far reaching effects on thinking and behaviour in ASD. Some explanations of autism, including current accounts of weak central coherence, see atypical information processing as running alongside other accounts of autism which seek to explain social deficits. Other accounts, such as those associated with underconnectivity, claim, however, that a tendency not to integrate information can explain all of the symptoms associated with ASD.

Whether the information processing style of individuals with ASD reflects a tendency, or whether they are incapable of integrating information, most accounts would agree that

individuals with ASD tend not to draw information together in order to process stimuli in context. Such a tendency raises questions regarding how people with ASD make use of background knowledge in thinking and reasoning in their daily lives. There has been very little work exploring everyday reasoning in ASD, and the studies presented here seek to address these questions.

A wealth of research into deductive reasoning among typical populations has shown that people are highly influenced by content and context when reasoning about the world (Evans, 2002). Such effects are typically referred to in the reasoning literature as a cause of ‘cognitive bias’, but the ability to take account of background knowledge and belief in everyday reasoning is highly adaptive and instrumental in achieving our personal goals (Evans, 2007). The experiments presented here use everyday conditional reasoning problems, with ‘if-then’ arguments. These problems have familiar content and have been extensively explored in terms of the influence of background knowledge and belief on reasoning outcomes (Evans, 2007; Evans & Over, 2004). Typically people integrate information presented with knowledge and beliefs about the world to place conditional reasoning problems in context. Where contextualized reasoning of this type occurs consistent changes in response patterns can be identified.

This kind of contextualized reasoning is subject to development. Very young children show little effect of background knowledge, and contextualized reasoning among typically developing youngsters develops through late childhood into adolescence (Markovits & Barrouillet, 2002; Markovits & Thompson, 2008). As adolescents move towards adulthood, the development of inhibitory and meta-cognitive processes allows for more control over reasoning and a more selective use of background knowledge (Markovits & Barrouillet, 2002; 2004; Muller et al., 2001). Typically developing adolescents, therefore, present a population which is arguably more influenced by background knowledge compared to younger children and adults.

Current knowledge about the integration of information in reasoning among individuals with ASD is limited. Available studies have tended to focus on counterfactual and rule-based reasoning relating to the social deficits in ASD. Such existing studies of reasoning suggest, however, that individuals with ASD may have difficulties with integrating perspectives, or drawing inferences on the basis of a given context. Information processing accounts of autism, such as Weak Central Coherence Theory and Complex processing Deficit Theory also predict that individuals with ASD will tend not to integrate background knowledge with presented material, in order to reason in context.

We surmised that a tendency not to integrate information in order to process information in context would result in atypical conditional reasoning performance, with regard to the influence of available background knowledge, among adolescents with ASD. We predicted that individuals with ASD would show less effect of background knowledge on reasoning outcomes; this was explored in Experiment 1. Subsequent experiments explored possible explanations for reasoning performance.

The rest of this chapter focuses on theories and accounts of autism. I will begin by outlining a domain specific account of autism relating to Theory of Mind, and more domain general deficits proposed under the umbrella of executive dysfunction. I will then go on to discuss a number of information processing accounts of autism which highlight detail based processing style in autism, and the tendency not to integrate information and process information in context among people with ASD. Chapter 2 will discuss relevant studies and theoretical accounts in the psychology of reasoning, which relate to the influence of knowledge and belief on thinking and reasoning, within typical populations.

Theory of mind

The vast majority of research into autism in the last four decades has involved an exploration of issues surrounding Theory of Mind (ToM) in some form or another. Theory of Mind is the

ability to understand that oneself and others have mental states including beliefs and intentions, and that behaviour can be predicted from knowledge of mental states (Premack & Woodruff, 1978). Children and adults with ASD have repeatedly been shown to have difficulties with Theory of Mind (see Baron-Cohen, 1993; 1995 for reviews). Theory of Mind is typically assessed using false belief tasks such as The Sally Anne Task. The child is shown a character 'Sally' who leaves an object (a toy or chocolate) in a basket before going out to play. In her absence another character 'Anne' moves the object to a new location (a box). Children are asked to say where Sally will look for the object when she returns to the room (Baron-Cohen, Leslie & Frith, 1985). Typically developing four year olds tend to succeed at this task saying Sally will falsely believe the object to be in the basket. Younger children and individuals with ASD tend to fail this task. There are numerous studies which demonstrate that children with ASD have a problem with carrying out false belief tasks such as the Sally Anne task. (See Baron-Cohen, 2000 for a review). This is typically taken to mean that they have difficulties in understanding the beliefs and desires of others. Children with ASD also have difficulties in inferring meaning from language outside of the literal, and typically, do not spontaneously exhibit imaginary play. These symptoms have all been taken as evidence for a lack of ToM.

Leslie is one of the major proponents of the ToM deficit account. Amongst others Leslie and Baron-Cohen have argued that autism is characterised by a kind of mind-blindness, involving a domain specific impairment to an innate module, leading to an inability to understand the mental states of other people (Baron-Cohen, Leslie, and Frith, 1985; Leslie, 1987, 1988, 1991; Leslie and Roth, 1993; Baron-Cohen, 1991, 1993). Leslie claims that around the age of two years children's representational skills move on from primary, literal representations of what exists in the world, and this is evident in imaginative play. Play involves simultaneous representations, one of the literal world and one of the play or fictional state. Leslie claims that this second state is in effect a manipulated representation of the first, so imaginative play is a form of metarepresentation. According to Leslie's account this early

ability is the precursor to understanding pretence in others. Understanding the beliefs and intentions of others (including pretence in self) constitutes a Theory of Mind. In order to quarantine the representations necessary for the understanding of belief or pretence these representations must be decoupled from the literal. The site for such decoupling is claimed to be an innate domain specific processor- the Theory of Mind Mechanism (ToMM). According to Leslie it is this mechanism that is damaged in some way in autistic individuals, leading to the social and communicative deficits individuals with ASD exhibit.

The ToMM account has been useful in explaining the social and language impairments associated with autism. Children with ASD show delays and deficits in their acquisition of language which range from a complete lack of language, to adequate use of language, but impairment in understanding the nuances of conversation associated with social meaning and intention. These pragmatic impairments in language have tended to be interpreted with regard to a lack of ToM (e.g. Lord & Paul, 1997; Wilkinson, 1998). The model presented is one where an innate mechanism fails to come online and has far reaching effects on social and linguistic development. A lack of ToM is, therefore, presented as the core dysfunction in autism. Language development, which relies upon joint attention and shared attention, is impoverished in autism and the typical understanding of pretense, beliefs and intentions, first in self then in others, fails to occur due to impaired metarepresentational performance of the ToMM. Where children with autism do have language it is linked to basic function and simple labeling (Tager-Flusberg, 1996). As the autistic child develops they exhibit a range of difficulties in conversational and social contexts due to the central Theory of Mind deficit.

The mind-blindness account of autism has been criticised on a number of counts. Most significantly perhaps, despite the claim that ToM impairment is a core deficit in autism, all children with ASD do not fail tasks taken to measure ToM; in fact in the initial testing session 20 % of participants were able to pass the Sally Anne Test (Baron-Cohen et al., 1985). This difficulty was addressed by investigating whether the ToM problem was a delay rather than a

deficit. Baron-Cohen (1989) claimed that although some individuals with autism could pass false belief tasks, none could pass a more difficult second order false belief task. This was subsequently found not to be the case (Bowler, 1992). The developmental delay account was supported, however, by the finding that performance on false belief tasks was related to verbal mental age. Individuals with ASD were found to be unlikely to pass such tasks until their verbal mental age was 12 or above (Happé 1995). A number of further tests such as the Strange Stories test (Happé, 1994) and the Eyes Task (Baron-Cohen, Jolliffe, Mortimore & Robertson, 1997) were developed in order to measure theory of mind among high functioning individuals with ASD. Individuals with ASD tend to do less well than controls on all of these tasks, they do not, however, show universal failure. This makes the idea of a domain specific impairment in a particular mechanism untenable.

Research into Theory of Mind among autistic groups has relied heavily on different versions of the false belief task. There is a wealth of evidence that people with ASD do not show typical ToM development, several studies have questioned, however, whether this particular task necessarily demonstrates a lack of understanding of belief. Other accounts of autism stress the underlying counterfactual nature of false belief tasks, the executive demands of such tasks and the failure of children with ASD on similar tasks, which do not rely on the understanding of belief.

Leslie's use of the term 'metarepresentation' may also be misleading to some extent (for a summary of the usage in autism research see Scott, 2001.) According to Leslie, basic metarepresentation, as shown in imaginative play, involves holding in mind a literal representation of the state of the world alongside a fictional representation which is derived from the first. The ToMM deals specifically with such metarepresentations, and ensures that fictional metarepresentations are insulated from the real world state. Criticism of Leslie's influential work has stemmed from the question of whether what he describes really constitutes metarepresentation, whether ToM necessarily involves domain specific

representational processes, and whether this kind of representational capacity is sufficient to explain performance on the false belief task (Perner, 1991; Whiten, 1996). Whiten and others for example, have disputed Leslie's claim that play involves metarepresentational abilities, whilst accepting that pretence involves:

‘A cognitive manipulation of already existing primary representations’

(Whiten in Sperber, 2000, p.156)

This leads to the discussion of what kinds of representations are involved in the false belief task. Whilst passing the false belief task necessarily involves representing differing perspectives there is some question as to whether performance relies on fundamental metarepresentational abilities which underlie the understanding of belief. Scott has argued that it is not necessary to metarepresent in order to solve false belief tasks at all (Scott, 2001). His definition of metarepresentation can be stated as a higher order representation of a representation. Scott claims it is not necessary to represent the fact that we have a belief in order to hold it. This implies that we can represent the belief of another without recourse to higher order representation, since higher order representation implies some representation of the content of the mental state. According to Scott what is necessary to solve the false belief task is to hold a representation of a belief as a proposition with two arguments, and recognise that belief may be true or false.

The ToMM impairment account was also called into question by the discovery that children with ASD do have problems with manipulating representations but this is unrelated to their ability to understand belief in others. Children with ASD were found to be able to solve simple false belief tasks that did not require representation of differing beliefs. Grant, Riggs and Boucher (2004), for example, found that children with ASD were able to solve non-standard false belief tasks which did not involve simultaneous consideration of differing

perspectives. The same children were found to perform poorly on physical state problems which did not involve the understanding of belief, but required holding differing possibilities in mind. This work is inconsistent with the claim that children with ASD fail false belief tasks due to an inability to understand the beliefs and intentions of others. Instead Grant et al. suggest that failure to pass false belief tasks is related to an inability to engage in complex reasoning about differing possibilities which requires the manipulation and integration of simultaneous representations. A number of accounts have also proposed that metarepresentation is a domain-general capacity of which Theory of Mind is just one example (Corballis, 2003; Perner, 1991; Stone & Gerrans, 2006).

Alternative accounts of ToM deficits in autism have also focused on a lack of innate early social processing (e.g. Stone & Gerrans, 2006). According to this account metarepresentational abilities are intact in autism but early social competencies such as joint attention and face and emotion recognition are impaired. ToM is thus impaired due to the impoverished development of precursor inputs. Related to this account is the Enactive Mind hypothesis (Klin, Jones, Schulz & Volkmar, 2003) which claims that the autistic mind lacks the innate drive to focus on the social world. This results in a tendency among individuals with ASD not to look for social meaning and consequently the development of social processing is impoverished.

Although people with ASD undoubtedly do have problems with Theory of Mind it is unlikely that this is the result of a domain specific metarepresentational impairment. Use of the false belief task has been confusing, as passing the task relies not only on understanding belief, but also on manipulating representations of differing perspectives. Work such as that of Grant et al. (2004) suggests that these abilities are distinct, and children with ASD may have domain general difficulties with tasks requiring high levels of representational complexity. Other accounts suggest that difficulties may stem from impoverished inputs to ToM processes due to the tendency not to attend to the social world during early development. Leslie's

domain specific account has proved inadequate, in explaining not only the social but also the range of non-social symptoms in autism, such as repetitive behaviour, obsessive interest and unusual islets of ability (Frith, 2001). New accounts tended to focus on more domain general explanations of the disorder. In some cases explanations strove to explain other aspects of autism, and in others domain general executive dysfunctions were presented as underlying social as well as other symptoms of autism.

Executive dysfunction

Whilst early studies of autism were concerned mostly with theory of mind, subsequent research focused on the possibility that autism could best be explained in terms of domain-general executive function. To some extent the social aspects of autism were left aside in these accounts. Executive functions can be conceived of as higher order processes that allow people to plan, sequence, initiate and sustain behaviour. Some accounts were presented alongside the ToM modular dysfunction account (Happé and Frith, 1995; Roth and Leslie, 1998), whilst others claimed that a TOM deficit among children with ASD was the result of domain general executive impairments (e.g. Harris, 1993; Hughes and Russell, 1993). Children and adults with ASD were found to have a number of executive impairments but findings were contradictory and inconsistent. For example, a variety of studies have explored specific executive abilities including planning, inhibition and set shifting. Individuals with ASD have been found to have deficits in planning, as shown by performance on The Towers of Hanoi or similar tasks (e.g. Ozonoff and Jenson, 1999). There are conflicting and problematic results in this area. Hughes, Russell and Robbins (1994) found that children with ASD were only impaired on more complex planning tasks. Other studies found that children with ASD who had low IQ performed poorly on planning tasks, but those with average levels of IQ did not (Mari, Castiello, Marks, Marraffa & Prior, 2003). In a comprehensive series of experiments (Ozonoff & McEvoy, 1994; Ozonoff & Strayer, 1997) Ozonoff and colleagues investigated

the inhibitory abilities of children with ASD, compared to normally developing children, matched for age IQ and gender. Children with ASD showed normal performance on a Go/No Go task, a Stop-Signal task and two negative priming tasks. Other studies have shown that autistic individuals have a problem with inhibiting prepotent responses. Individuals with ASD perform poorly on the windows task, for example, which requires the participant to point or reach for an object (Hughes and Russell 1993).

Children and adolescents with ASD are also repeatedly found to be highly perseverative on the Wisconsin Card Sorting Task, taken to be a measure of set shifting, compared to normally developing participants (e.g. Ozonoff & Jensen, 1999), and other clinical groups (e.g. Bennetto Pennington & Rogers, 1996). There have been few, if any, other set shifting tasks conducted with children with ASD, however, and some significant differences on the Wisconsin Card Sorting Task do not appear when the effects of verbal IQ or full-scale IQ are removed (Hill 2004). This task is also known to have an inhibitory component, so it is difficult to isolate specific executive impairments (Konishi, Nakajima, Uchida, Kikyo, Kameyama, & Miyashita, 1999).

Studies focusing on the general working memory abilities of participants with ASD also show conflicting and problematic results. Bennetto et al. (1996) found that participants with ASD performed poorly, compared to matched controls, in temporal order memory, source memory, sentence and digit span. Children and adults with ASD also show poor performance on spatial working memory tasks (Luna, Minshew, Garver, Lazar, Thulborn, Eddy & Sweeney, 2002). Ozonoff and Strayer (2001) looked at a number of executive tasks, however, and found mixed results on working memory tasks amongst children with ASD. They concluded that conflicting results reflected task administration factors, and children with ASD did not suffer from working memory deficits.

Overall, the executive deficit account of autism suffers from a confusing array of results. Task use has tended to be repetitive in that there is not a wide range of tasks used to measure

different functions. The specific executive functions implicated in certain tasks are also not always well defined. Executive functions may not be completely unitary with varying combinations of executive functions involved in solving executive tasks (Miyake, Friedman, Emerson, Witzki & Howeter, 2000). Commonly used tasks such as the Towers of Hanoi or the Wisconsin Card Sorting Task are likely to draw on more than one executive function. The inconsistent results on executive tasks by individuals with ASD may also reflect differences in IQ or unusual compensatory processes. Individuals with ASD have been shown to have different large scale brain networks (Koshino, Carpenter, Minshew, Cherkassky, Keller & Just, 2005), for example, with working memory shifted towards regions typically associated with lower levels of cognitive processing, including the left inferior temporal, left temporal, right temporal, and left inferior extrastriate.

Like The ToM account the executive deficit hypotheses cannot account for the full range of autistic symptoms, and the combination of the two approaches seems less than fruitful. It is possible that inconsistent executive dysfunction is a symptom of other causes of the core features of autism. Recent neuroimaging data suggests that the problem may more specifically lie in a communication problem between frontal and other brain regions, rather than executive dysfunction per se. Recently, information processing accounts of autism have also explained the range of abilities and impairments in autism with reference to processing style rather than executive deficits.

Weak central coherence and related theories

A number of current theories about the nature of autism focus on an inability to contextualise or integrate information. Weak Central Coherence Theory (Frith, 1989) stems from the observation that individuals with ASD tend to focus on parts of objects, rather than the whole, and show an unusual sensitivity to small changes in the environment. Frith found that individuals with ASD showed good or superior performance, compared to controls, in the

Embedded Figures Task (Shah & Frith 1983). In this task participants have to identify a shape from a wider whole. Typically people find this task difficult, as they tend to process the shapes presented globally, rather than as a series of parts. Frith claims that usual performance on the Embedded Figures Task stems from the fundamental drive to process information in context in order to arrive at higher meaning or central coherence. Typically people tend to create an impression of a whole from which details can be reconstructed, rather than deal with information in a piecemeal fashion. Frith claims that people with ASD exhibit weak central coherence. This processing bias leads to a failure to process information in context in order to extract the gist of a given situation and an over-reliance on piecemeal or detail-based processing where abilities may be enhanced compared to the typical population.

In the original incarnation of Weak Central Coherence Theory a lack of global processing was presented as the core deficit, with enhanced attention to detail being a consequence of a lack of global interference. Further studies identified examples of enhanced identification of localized visuo-spatial details in ASD, such as a reduced effect of inversion compared to the typical population in face processing (Langdell, 1978, Hobson, Ousten, & Lee, 1988) and good performance on the Block Design Test (Shah & Frith, 1993). At the same time evidence for a lack of contextualized processing was identified by poor performance on tasks which require the integration of details, such as the disambiguation of homographs (Frith & Snowling, 1983; Joliffe & Baron-Cohen, 1999a), and the interpretation of words in ambiguous sentences (Joliffe & Baron-Cohen, 1999b). Both these types of evidence were taken as support for a global processing deficit. Weak central coherence was originally conceived as providing a general explanatory framework for the symptoms associated with autism. Problems with integrating information in order to create new meaning were taken to underlie patterns of abilities and impairments associated with autism, including deficits in social understanding.

There have been a vast number of studies related to weak central coherence across a number of widely differing cognitive and perceptual tasks (see Happé & Frith, 2006 for a

review). These studies have identified both relatively robust findings in some areas and conflicting evidence in others, and have led to revisions in the initial conception of the account. There is a large and reliable body of evidence that people with ASD show good or enhanced performance on tasks which require local or detail based processing. Evidence for a deficit in global processing is more complex, however. It is now recognized that people can have good attention to detail without necessarily having poor global processing, this has led to reassessments of findings.

Other contemporary accounts recognize atypical processing at both local and global levels but also tend to emphasize enhanced local processing. The enhanced perceptual functioning account proposed by Mottron and colleagues (e.g. Mottron & Burack, 2001) claims that individuals with ASD show over-developed low-level processing of sensory material which is linked to localized brain areas dealing with specific perceptual material. An inability to draw together information from disparate areas of the brain leads to an over dependence on domain specific perceptual processing, where abilities may be enhanced. Compensatory pathways for higher level perceptual processing are typically domain general and are associated with distributed networks across the brain. Enhanced low level perceptual processing is taken to explain for example, superior recognition of visual patterns, obsessive and restricted interests and identification of small changes in the known environment.

Plaisted and colleague's (O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001) work on feature discrimination in ASD also identifies superior processing of the features unique to an object, but poor processing of the features held in common between objects. Key research focuses on enhanced processing of local features, but evidence of reduced integration in feature processing across domains is less clearly defined (Plaisted, O'Riordan, & Baron-Cohen, 1998a ; Plaisted, O'Riordan, & Baron-Cohen, 1998b).

There is growing evidence from studies with typical individuals that global and local processes are distinct with separate developmental trajectories (e.g. Reyna and Kiernan, 1994;

Burack, Enns, Iarocci & Randolph, 2000; Porporino, Shore, Iarocci & Burack, 2004). The difficulty with many tasks taken to measure weak central coherence is that outcomes can be interpreted as implying poor global processing, enhanced local processing or both (Happé & Booth, 2008). There are very few tasks which measure local and global processing separately and recent examples still show mixed results. Mottron, Burack, Iarocci, Belleville and Enns (2003) used a battery of tasks in an attempt to assess local and global processing separately in ASD and concluded that global processing was intact but individuals with ASD were better able to ignore global influence where it was irrelevant to the task in hand. Booth's (2006) battery of tests included tasks designed to specifically measure global integration, as distinct from local processing. In this case evidence was found for poor integrative processing among individuals with ASD. People with ASD seem to be able to integrate information to achieve meaning in specific cases. They are able to integrate information about a given object (Ameli, Courchesne, Lincoln, Kaufman, & Grillon, 1988; Pring & Hermelin, 1993) or routine in their daily life, for example. Connecting information in these tasks may depend upon item to item associations or chaining. Integrating information within a single domain may also be intact, where integrating information across domains may not (Happé & Frith, 2006). There is also evidence that people with ASD are able to attend to global features, for example in a hierarchical figures task, when instructed to do so (Plaisted, Swettenham & Rees, 1999). For these reasons weak coherence has recently been conceptualised as a detail focused processing style with a tendency not (rather than an incapacity) to process information in context.

Investigations of the link between social deficits and weak central coherence have been mixed. The latest incarnation of Weak Central Coherence Theory acknowledges that social and non-social aspects of the disorder may be independent, and weak central coherence may not provide a causal role underlying patterns of social behaviour. Weak central coherence and ToM performance, for example, have been found to be unrelated in a number of studies (Happé, 1997; Joliffe and Baron-Cohen 1997; Morgan, Maybury and Durkin, 2003). These

findings may reflect the confound between local and global processing on weak central coherence measures, however, and Happé and Booth (2008) suggest that poor integrative processing may be related to social deficits, but enhanced local processing may not.

Weak central Coherence Theory has been refined over the years on the basis of the vast body of related experimental findings. In recent accounts, for example, it is recognized that weak central coherence may not play a causal role in the social impairments associated with autism. A piecemeal processing style, manifest in attention to details or parts, seems experimentally robust, and this has replaced global coherence as the focus of the account. It is now generally recognized that detail-based processing and poor global processing do not necessarily go hand in hand. The fact that this was previously thought to be the case has influenced task design, and made interpretation of performance difficult in some cases. There is evidence that individuals with ASD may be able to integrate information to arrive at higher meaning in response to some tasks, or under explicit instruction. For these reasons weak central coherence is presented as a tendency not to draw information together for higher meaning, rather than incapacity to do so.

The mechanisms underlying weak central coherence are not currently clearly defined. Accounts tend to focus on atypical brain function including abnormalities in specific pathways (e.g. Spencer et al., 2000) or brain regions (Waiter, Williams, Murray, Gilchrist, Perrett & Whiten, 2005) and reduced connectivity across brain regions (Brock, Brown, Boucher & Rippon, 2002; Just et al., 2004). The underconnectivity account proposes that autism is a cognitive and neurobiological disorder resulting in a problem with integrating information and a reliance on lower level processing. Function of individual brain areas are preserved and may even be enhanced, but the integration necessary for higher levels of cognitive processing is impaired.

Underconnectivity and Complex Processing Deficit Theory

Reduced connectivity between brain regions in autism has been proposed as the mechanism underlying weak central coherence, but the underconnectivity account has also been put forward as a theory of autism in its own right (Just et al., 2004). Weak Central Coherence Theory, Underconnectivity Theory and other related accounts, such as Complex Processing Deficit Theory, are all relevant to the studies presented in this thesis, as they are all concerned with integrating or contextualising information. There are, however, differences in emphasis between these accounts in terms of how information processing is conceptualised. Other differences include methodological approach and the degree to which the range of symptoms associated with autism are included in explanatory frameworks. This section will seek to outline underconnectivity and complex processing deficit accounts and how these accounts interrelate with aspects of weak central coherence.

The model of the mind presented by Underconnectivity Theory is one of interrelated specialised cortical centres, with coherence emerging from coordination of brain regions. Higher level controlled forms of thought may be facilitated by integrative frontal regions, and any process which requires high levels of contribution from frontal executive regions is likely to be disrupted. This is not to say that all integration that emerges is imposed by central areas, however. Neuroimaging studies such as that of Just et al. (2004) examine levels of collaboration between brain areas (functional connectivity), based on correlations between activation of voxels using Pet or more recently fMRI scanning. The implication is that patterns of activation which match each other, in differing brain regions, reflect communication between those regions. Such studies show that participants with ASD display lower levels of connectivity than controls, when engaging on a number of tasks including ToM tasks (Castelli, Frith, Happé & Frith, 2002), sentence comprehension tasks, and performance on the Tower of London problem solving task (Just et al., 2004). There is also some evidence that impairment in connectivity may be uneven, and associated specifically with

cortical-cortical connections, whilst subcortical-cortical connections show hyperconnectivity (Mizuno, Villalobos, Davies, Dahl & Müller, 2006). This tendency is reflected in specific under activation in areas associated with complex processing and integration of information. For example, Just et al. found that in the sentence comprehension task, in addition to general underconnectivity, individuals with ASD showed more activation in an area associated with lexical meaning of individual words, and less in areas associated with semantic and working memory processes.

Explanations for the underconnected brain rely upon a model of development such as that presented by Karmiloff-Smith (1998), where the infant brain is relatively unspecialised apart from a few hardwired areas. Development involves a balance between specialisation and integration. Brock et al. (2002), For example, claim that underconnectivity stems from abnormal development of integration between disparate brain regions. In the infant with ASD, specialisation occurs but integration between brain areas is impaired. Levels of impairment reflect levels of autistic functionality. In explaining how brain regions communicate, Brock et al. refer to current debates concerning temporal binding which suggest that communication may involve combination coding or temporal coding, depending on the complexity of the task. Combination coding deals with lower level processing such as the representation of object features, whilst temporal binding is necessary for higher level information processing. Brock et al. claim that it is the capacity for temporal binding that is lacking in individuals with ASD.

Underconnectivity Theory, as presented by Just et al. (2004), differs from current Weak Central Coherence Theory in that underconnectivity is presented as explaining all symptoms of autism, including social impairments. Underconnectivity Theory accounts for the ToM deficit (and many other deficits such as those involving language comprehension) in terms of an inability to meet the large demands of information integration that would be needed to understand complex social situations, involving a high level of representational manipulation.

This difficulty would hold for any domain, not just the social, explaining apparent executive function impairments. Set shifting, for example, where processing has to move from one coordinated network to another, would be problematic. Hence autism is characterised by impaired performance on complex cognitive tasks that rely on high levels of integration, and preserved or enhanced performance on lower level tasks with a dependence on local processing. Lack of brain connectivity has several implications related to how people with ASD think and behave. Any task requiring the integration of information, to arrive at higher meaning, is likely to be impaired. Both Underconnectivity Theory and Weak Central Coherence Theory imply, however, that individuals with ASD will tend not to integrate information in order to process stimuli in context in any domain; either due to an inability to do so, or due to a particular processing style.

Other accounts related to underconnectivity and resulting integrative difficulties include Complex Processing Deficit Theory (Minshew, Goldstein & Siegel, 1997; Minshew and Goldstein, 2001; Williams, Goldstein & Minshew, 2006a) which proposes that adults and children with ASD have a general impairment in processing complex information. A difficulty in drawing information together in order to create concepts and schemas means that incoming information cannot be processed with the support of a contextual framework. This impairment is only apparent in tasks which draw on limited cognitive resources. Less complex tasks or those which generally make fewer demands on cognitive resources will be unimpaired. The claim is not that individuals with ASD have a problem with cognitive capacity per se, just that their more piecemeal processing approach, without top down supportive mechanisms, makes overwhelming cognitive demands when engaged in effortful, complex tasks. According to Minshew and colleagues, higher level tasks can, therefore, be defined as those which rely upon employment of limited cognitive resources. A difficulty in processing complex information results in a late information processing disorder. Early processing performance may be intact, or may be enhanced compared to the typical population, but more complex

processing demands cannot be met due to an inability to integrate information, necessary for higher levels of thinking.

Minshew et al. (1997) addressed the question of what constitutes complex processing directly in an early empirical study of performance on simple and complex tasks within a number of domains. A large battery of tests was presented including tasks in memory, motor skills, language and reasoning. In each domain tasks were presented with varying levels of complexity. Participants with ASD demonstrated impairment in complex or late processing, but intact or superior function at lower level or early processing. This pattern was demonstrated across domains with the exception of visual-spatial processing. Poor performance was most pronounced in those domains that placed the highest demands on cognitive capacity and integration of information: the social, communication, and reasoning areas. A similar study was later repeated with children with ASD (Williams, Goldstein & Minshew, 2006a) with similar findings. Children with ASD showed unusually poor performance compared to matched controls in tasks tapping complex processing in sensory perception, motor, language, and memory. As with the adults in the previous study, the children with ASD had most difficulty on tasks that placed the highest demands on integration of information such as memory recall for large amounts of complex material and text comprehension.

Minshew and colleagues' account has strong parallels with Weak Central Coherence Theory; both accounts would agree that individuals with ASD have a reliance on piecemeal processing, and a tendency not to integrate information for higher meaning. The complex processing deficit account shows how this processing style is likely to interact with cognitive capacity and memory functions, resulting in a lack of supportive models and schemas. Not only do individuals with ASD tend not to process stimuli in presented contexts they also fail to create internal contextual frameworks which can alleviate processing demands of complex tasks. Whilst an over-reliance on detail-based processing can afford some benefits, according

to this account the general outcome of such a processing style is rapid working memory overload. This account implies a distinction between tasks relying upon associative and implicit levels of processing, which should be intact in autism, and tasks which rely on working memory. Working memory dependent tasks tend to require high levels of integration of information and consequently will not lend themselves to a piecemeal processing style. Minshew, Goldstein and Siegel (1997) found impairment in a range of complex language tests including the Reading Comprehension subtest from the Kaufman-Test of Educational Achievement, the Verbal Absurdities subtest from the Stanford-Binet Intelligence Scale and the Token Test. These tests explore complex higher order features of language likely to involve working memory, such as text comprehension, verbal problem solving, and the comprehension of complex grammatical constructions. At the same time intact simple language processing is demonstrated by performance on WAIS-R Vocabulary test, K-TEA Reading Decoding task and the Controlled Oral Word Association (FAS) task. All of which largely rely on implicit associative processes.

In later studies specifically exploring memory function in adults, adolescents (Williams, Goldstein, & Minshew, 2005) and children with ASD (Williams et al., 2006b) it was found that basic associative memory abilities were intact, but the use of cognitive frameworks to support memory was impaired. These impairments were progressively worse as the complexity of the material increased for both auditory and visual material.

Previous studies focusing on memory impairments of individuals with ASD have been explained with reference to executive deficits (e.g. Bennetto et al., 1996; Russell et al., 1996). Findings are typically conflicting and problematic. The complex processing deficit account may provide a more useful framework for understanding memory abilities in ASD. Children with ASD do not appear to spontaneously use context to support memory, for example, and organisational strategies such as the use of semantic categories appears to be lacking, unless prompted by external cues (e.g. Frith 1970a 1970b Fyffe & Prior, 1978; Tager-Flusberg, 1991).

Failure to spontaneously use contextualised processing means that memory for complex configural material such as conversations, social events or stories may be poor whereas memory for lists of items or digits may be good (e.g. Fein et al. 1996; Boucher, 1981).

Underconnectivity theory and the complex deficit account may also shed some light on the mixed findings for global processing in ASD. Both would predict that individuals with ASD are capable of integrating information in some circumstances where communication between brain regions is minimal or where cognitive demands are not high. For example, integrating information about the features of a given object may not require high levels of communication between disparate brain regions. Integration of information which relies on chains of simple implicit associations such as picture sequencing may also place only minimal demands on the cognitive system. Where cognitive demands are high, individuals with ASD may quickly become overwhelmed by the effort required to process information without supportive contextual frameworks. Nevertheless, individuals with ASD may be able to engage in some demanding tasks where they are motivated to employ additional effort to do so. Further evidence for integrative difficulties, specifically relating to the cognitive demands of the task at hand, come from other areas of research into autism such as text comprehension and the formation of complex situation models.

Text comprehension and verbal processing

Further information about the ability of individuals with ASD to integrate information comes from studies of text comprehension. Aspects of reading in autism appear to be intact, but individuals with ASD have difficulty using context in reading, and generally appreciating the meaning of texts (e.g. Frith and Snowling 1983; Happe', 1997). This difficulty is typically related to central coherence and difficulties with integrating information. Studies exploring text comprehension amongst individuals with ASD demonstrate a specific processing problem relating to the integration of background information with online presented material. As

predicted by complex processing and underconnectivity accounts of autism individuals with ASD are able to integrate information in some cases, in order to make simple inferences and judgments, for example, with regard to a given text. Saldana and Frith (2007) found that individuals with ASD were able to draw on associative processes in order to activate relevant world knowledge and make implicit inferences which influenced subsequent responses. Saldana and Frith, therefore, conclude that the problems in text comprehension exhibited by individuals with ASD must reflect higher level processing.

Other studies on text comprehension among individuals with ASD focus on these higher level processes. The work of Joliffe and Baron-Cohen (1999a; 2000) suggests that individuals with autism have impairment in integrating presented information with background knowledge in order to arrive at ongoing deep text comprehension. This deficit is demonstrated in a number of tasks including the use of context to interpret ambiguous sentences (Joliffe and Baron-Cohen 1999a), and the ability to integrate story information to arrive at global inferences which allow for the accurate interpretation of character actions (Joliffe and Baron-Cohen, 2000). Participants with ASD were able to answer questions about the text, however, requiring basic bridging inferences. They were also able to use temporal cues to arrange sentences.

Joliffe and Baron-Cohen describe this impairment in terms of the weak central coherence account. A difficulty in achieving global coherence, means making causal connections between disparate information in order to arrive at local then higher level meaning does not occur. Complex comprehension necessitates integration of information at several levels (Zwaan and Radvansky, 1998), including explicit and implicit processes. Whilst it seems that some level of activation of knowledge and text comprehension is intact in autism, reflected in the ability to form simple implicit bridging inferences, the kind of fluid, explicit, effortful integration of information needed for deep on-going text comprehension is evidently impaired.

Individuals with ASD may not only exhibit an atypical processing style compared to typical controls, but this may be related to a reliance on less demanding representational modalities. In the typical population, the integration of information across domains may rely upon verbal as opposed to visual processing of information. There is evidence, however, that people with ASD prefer visual rather than verbal processing.

Individuals with ASD tend to show particularly good performance on visual search tasks and tasks requiring the analysis of visuo-spatial details, such as the block design and object assembly subtests of the Wechsler intelligence test. Neuroimaging studies (e.g. Koshino et al., 2005) also show activation during executive tasks in areas associated with visual processing among participants with ASD, whereas controls show activation in areas associated with verbal processing. Individuals with ASD, more generally, show greater activation in posterior regions of the brain and the right hemisphere across a number of tasks (e.g. Koshino et al., 2004; Muller et al., 1999). This supports a tendency to rely on non-verbal processing. These findings are in line with firsthand accounts of the syndrome by high functioning individuals with ASD. Temple Grandin (1995), for example, claims that she thinks in pictures. She can think through problems in visual form and uses visualisation to aid understanding of concepts. As well as a tendency for a visual processing bias there is some supporting evidence that individuals with ASD have impairment in their use of inner speech (Whitehouse, Maybery & Durkin, 2006). This is of interest, since inner speech has been proposed as the medium through which information is integrated in the brain.

Carruthers (2002; 2009) claims that inner speech, in the form of natural language, constitutes the medium of conscious propositional thought and is, in itself, responsible for modular integration in thinking and reasoning. Thoughts may take the form of natural language or of models or imagery, but it is language which specifically serves to integrate relevant information. Carruthers claims that language is the medium of integrative non domain specific thought and inference. This integrative capability is possible as language is an

input and an output system. Briefly stated, language needs access to a vast array of information, housed, according to Carruthers in separate domain specific modules, in order to comprehend, compose and output speech. It is this that makes it possible for language to access implicit modules, integrate information and broadcast complex representations, in an internal variant of speech itself, back to central modules.

If Carruthers is right then a lack of inner speech among individuals with ASD is likely to go hand in hand with a lack of modular integration. The question here becomes one of chicken and egg, however. Lack of brain connectivity is likely to affect the development of complex language, where comprehension relies upon contextualisation and inference of meaning. Complex linguistic processing would necessarily go beyond simple lexical encoding and involve integration of disparate brain networks. Resulting impoverished inner speech, according to Carruthers, would also lead to further difficulties in contextualised thinking and drawing together information in relevant ways. Compensatory mechanisms and hyperconnectivity in some brain regions may lead to superior visual processing abilities and enhanced early processing where low levels of integration are required.

Carruthers (2009) stresses the importance of central broadcast and exchange of information. Of particular importance is the inter-relationship between language and one central module, Theory of Mind. So, in a sense, we return to where we started from. This relationship is crucial, since the comprehension of language relies heavily on ToM inputs, and also because one of the primary inputs in ToM processing is language. Carruthers also claims that mind reading faculties are crucial to the kind of complex internal integrative processes involved in metarepresentational conscious thinking. There is a large literature concerned with the relationship between Theory of Mind and communication (e.g. Happé & Loth 2002; Papafragou, 2002) and the link between Theory of Mind and language is well established. According to this account, ToM would necessarily be impoverished in a system with low level atypical connectivity and a lack of inner speech; where the reciprocal links of broadcast and

exchange between central brain regions were not supported. This idea is quite different to Leslie's ToMM account. Here the core deficit is one of connectivity between modules, not dysfunction of any particular module. Lack of connectivity is implicated in the social and communicative deficits associated with autism, as well as contextualised thinking and complex processing across many domains. At the same time compensatory mechanisms, such as a reliance on visual processing strategies and atypical brain development, may account for unusual islets of ability and superior or good performance on tasks which require, for example, visuo-spatial processing or the identification of details regardless of the global picture.

Conclusion

Current theories of autism tend to focus on the effects of a domain general information processing style on thinking and behaviour. Whilst there is some disagreement about whether such an approach can account for all of the symptoms associated with ASD, there is much consensus about the nature of information processing in autism. Most accounts would accept that individuals with ASD tend to see the world in terms of details or parts, and show good or enhanced local processing as a result. A 'persistent preoccupation with parts of objects' is one of the current diagnostic criteria for ASD (DSM-IV, APA, 1994). There is also agreement that individuals with ASD tend not to integrate information in order to process stimuli in context. There is evidence, however, that people with ASD can integrate information in some circumstances. The ability to draw information together for higher meaning may be related to the degree of integration required, the cognitive demands of the task at hand, or alternative compensatory processes available to the individual. The mechanisms underlying this processing style are likely to be related to atypical brain development. Several studies suggest that individuals with ASD have reduced connectivity between brain regions.

Accounts such as Underconnectivity Theory and the complex processing deficit account have been presented as an explanation for all of the symptoms associated with autism, resulting in difficulties performing complex tasks in any domain which rely upon integrative processing. Any area of thinking or behaviour is likely to be disrupted especially where the cognitive demands of the coordination of brain regions is high. Although studies of reasoning among autistic populations are limited, those that exist, along with Weak Central Coherence Theory, would predict that the drawing together of information necessary for reasoning on the basis of knowledge and belief is likely to be impaired in this population. Chapter 2 will examine the deductive paradigm in the psychology of reasoning relevant to the development of tasks which demonstrate the influence of content and context on reasoning performance. Dominant theories seeking to explain these influences, including, logicism, Mental Model Theory and Dual Process Theory, will be outlined. Evidence for the effects of background knowledge and belief on syllogistic and conditional reasoning will be explored and the development of conditional reasoning will also be discussed.

Chapter 2

Introduction

In this chapter I will examine the deductive paradigm in reasoning, and the development of psychological interest in the role of background knowledge and belief in reasoning. I will discuss relevant theories concerned with explaining reasoning performance, and evidence for the influence of content and context on that performance. I will explore the influence of available knowledge on everyday conditional reasoning, and the development of conditional reasoning. I will begin by describing some basic concepts involved in reasoning research.

The psychology of reasoning is involved with understanding how people form conclusions, inferences, or judgments. Reasoning can be either deductive or inductive. Inductive inference involves adding new information to what is presented whereas deductive inference is based only on material presented and what is implicit in it. The psychology of reasoning has largely been concerned with deductive reasoning and tends to use a methodology known as the deduction paradigm. Typically, participants are presented with verbal statements, told to assume that they are true and asked to produce a conclusion or evaluate whether a conclusion necessarily follows. The content of reasoning problems may be abstract (all As are B), factual (if the ignition key is turned, then the car will start), contrary to fact (if it is raining, then the road will be dry) or counterfactual (if I had caught the train, then I would have got there on time). Reasoning problems can be presented in a number of different ways and take several forms. In the studies presented here we are mainly concerned with conditional reasoning. Conditional reasoning is common in a range of contexts including everyday thinking as well as abstract or scientific problem solving.

Conditional reasoning involves inference with a major premise of the form 'if p then q' and four possible minor premises; Modus Ponens (MP), Modus Tollens (MT), Affirmation of the Consequent (AC) and Denial of the Antecedent (DA). Both MP and MT are valid

inferences, as there is a single logically correct response. AC and DA are invalid inferences, as the correct logical response is one of uncertainty. In the case of the invalid inferences AC and DA, however, there is a tendency for people to respond with certainty by giving the pragmatically implied conclusion 'p is true' for AC and 'q is false' for DA (See Table 1). The implied responses are not logically correct.

Table 1 Examples of valid and invalid conditional inference forms

Validity	Argument form	
Valid	Modus Ponens (MP)	Modus Tollens (MT)
	<i>If P then Q</i> : If it is sunny, then Joe goes out	<i>If P then Q</i> : If it is sunny, then Joe goes out
	<i>P</i> : It is sunny <i>Q</i> : Joe goes out	<i>Not Q</i> : Joe does not go out <i>Not P</i> : It is not sunny
Invalid	Affirmation of the Consequent (AC)	Denial of the Antecedent (DA)
	<i>If P then Q</i> : If it is sunny, then Joe goes out	<i>If P then Q</i> : If it is sunny, then Joe goes out
	<i>Q</i> : Joe goes out <i>P</i> : It is sunny	<i>Not P</i> : It is not sunny <i>Q</i> : Joe does not go out

An example of an AC argument with abstract content would be;

If there is a 3, then there is a W

There is a W

In this case it logically follows that there may or may not be a 3, although most people conclude that it follows that there is a 3. (We will talk more about this in the section on conditional reasoning.)

The study of the effect of background knowledge and beliefs on reasoning has also tended to focus on syllogistic reasoning. Categorical syllogisms include two premises and a conclusion. The first premise and the conclusion are linked together by the second premise. An example of an abstract syllogism would be;

All A are B

All B are C

Therefore, all A are C

Generally people are asked to engage in deductive reasoning in order to assess logical arguments, or derive logical conclusions from the statements they are presented with. The use of the deductive paradigm in reasoning research stems from philosophical traditions which present logic as underlying rational thought (Henle, 1962). A wealth of studies, particularly in syllogistic reasoning, have demonstrated, however, that even when people are instructed to reason according to logic they find it difficult to ignore their knowledge and beliefs about the world (Evans, 2002; Chater & Oaksford, 1999; Oaksford, Chater & Larkin, 2000; Gigerenzer, 1996). The influence of belief on reasoning has been conceptualized in different ways but generally belief based responding is thought to be the result of cognitive biases. Such belief bias has been taken as evidence for error in logical performance or as demonstration of irrational thought patterns. More recently, however, it has been recognized that reasoning on the basis of logic may be a rarified form of reasoning which, rather than forming a blueprint for human thought, is effortful and error prone, even for highly educated adults. Recent accounts of everyday reasoning suggest that it is, by default, contextualized, and is characterized by the integration of all relevant knowledge and belief. Contextualized reasoning of this sort has been presented as being highly adaptive and helpful in achieving personal aims (Evans, 2007). Nevertheless, most reasoning tasks still rely on the deductive paradigm, the origins of which can be traced back to logicist principles.

Logicism and mental models

The standard deductive form of reasoning research originated with the philosophical tradition of logicism; this can be traced back as far as Aristotle who presented human beings as rational animals. The tradition associated with this view concerns reasoning according to rules of logic. According to logicism, thinking is by nature rational, and rationality is characterized by logic. The idea that human thought is governed by logic was embraced by Piaget (e.g. Inhelder & Piaget, 1958). Piaget's ideas were very influential in the psychology of reasoning in the 1960s and 70s, and reinforced the conception of reasoning as intrinsically logical in nature (Henle, 1962; Smedslund, 1970). Piaget claimed that knowledge and cognition develop through a number of stages with formal operational thought being the final stage. Thinking moves from being tied to concrete objects towards abstract logical thought. At the formal operational stage, people can take thoughts about objects and events, and abstract from them propositions and statements about their logical relationships. Within the field of reasoning the deductive paradigm developed in order to investigate people's logical competence, influenced by the work of Piaget, and based on standard logics developed by mathematicians such as Frege (1952).

Problems devised on the basis of standard logics began to be used regularly by psychologists studying reasoning, but the results showed that people often performed poorly on these tasks. So much so that it was questioned whether most adolescents, or even adults, had achieved the formal operational stage of logical thought. These findings led to a backlash in the field resulting in claims that people were intrinsically irrational and did not reason according to logic at all. The most notable example of work at this time was that of Peter Wason. Wason developed two important tasks, the 2-4-6 task (1960) and the four card selection task (1966), which demonstrated that people were prone to systematic biases in reasoning. A large number of studies have explored performance on variants of the selection task (See Evans & Over, 2004, Chapter 5, for a review). Participants are asked to choose

which of four cards they need to turn over to decide whether a statement holds or not. Four cards are shown with only one side exposed. In the original version participants are told that all the cards have a number on one side and a letter on the other. The following numbers and letters can be seen:

A D 3 7

They are then told the following rule about the information on the cards:

If there is an A on one side of the card, then there is a 3 on the other side of the card.

Participants are asked which cards they need to turn over in order to discover whether the rule is true or false. Logically the statement is proved to be false by finding a card which has an A on one side and a number which is not 3 on the other. The correct logical response is, therefore, to turn over the cards showing A and 7. The vast majority of adults fail this version of the task, and resort to simply choosing the cards that are mentioned in the rule (Evans, 1998). Typically, therefore, people turn over the A card alone or the A and the 3 cards. Wason claimed this was due to the fact that people were trying to prove the rule true rather than false, hence they exhibited an erroneous confirmation bias by turning over the cards which could confirm the rule. There have been other accounts of the selection task since, but at this time what was deemed to be of importance was that people were not reasoning according to logic. These findings were taken to show that irrationality was the norm in human reasoning. At the time, psychological debate revolved around the question of whether people were logical or not. Logic remained the normative standard against which to assess how rational people were when engaged in reasoning. This led to a paradigm-bound perspective with regard to reasoning on the basis of background knowledge and belief. Where such reasoning was illogical it tended to be conceptualised as either due to error or bias.

Wason's work influenced both theories based on logicism, which were forced to accommodate the actual performance of people on logical tasks, and new accounts of reasoning which highlighted the role of context in reasoning. The growing empirical evidence

in the field of reasoning led to the development of two theories which seemed to be in opposition. On the one hand theorists in the tradition of logicism (e.g. Braine & O'Brien 1998; Rips, 1994) claimed that human thought was based upon application of a set of inference rules held in the brain, and reasoning involved identifying the basic structure of a problem and applying logical rules or schema. An example of an abstract inference rule for MP would be:

If p then q

P

Therefore q

This kind of rule could be applied to any MP problem regardless of content. Hence given the premises:

If the key is turned, then the engine will start

The key is turned

P is translated as 'the key is turned' and q is read off as being equivalent to 'the engine will start.' In response to the evidence that people often had difficulty with deductive reasoning, such theories also acknowledged that this process was often error prone. Belief based responses to reasoning problems were, therefore, defined as bad reasoning, or errors in the underlying logical nature of the reasoning process.

An alternative and concurrent account, mental model theory (Johnson-Laird 1983; Johnson-Laird and Bara, 1984; Johnson-Laird & Byrne, 1991), proposed that the errors that people made on logic based problems should form the basis of further study. Johnson-Laird and colleagues claimed that reasoning was influenced by the content of the problems presented. Mental model theory put forward the idea that people created models or mental structures of given problems in order to solve reasoning problems. This account implies that people have some intrinsic understanding of the validity of arguments and suppose that an inference cannot be valid if the premises are true but the conclusion is false. People, therefore,

set up a model where the premises are true and search for counterexamples where the conclusion does not hold. Inferences are made by examining models about possible real world states. A conclusion will be accepted if it is represented in a model and not contradicted by other models. The manipulation of models involves working memory, which mediates reasoning performance.

One of the major differences between mental model theory and the accounts that preceded it was the recognition that people would draw upon what they knew to be true about the world, in order to derive models of reasoning problems, without recourse to logical rules. Nevertheless, it has been suggested that mental model theory and theories based on logicism have fundamental underlying similarities (e.g. Oaksford and Chater, 1995; Evans and Over, 2004). Both theories rely on the same deductive paradigm and employ logical reasoning instructions, but, more importantly, mental model theory strives to explain the mechanisms underlying logically valid deductive inference, and assumes that this is the primary form of reasoning. The mental model account, therefore, implies that reasoning is involved with the search for validity and as such is potentially logical, although in practice it is error prone. The limits of cognitive capacity may mean that insufficient models lead to defective reasoning outcomes, or beliefs may interfere with the effective search for counterexamples (Johnson-Laird & Byrne, 1991). Evans and Over (2004) further stress the lack of consideration of assessments of probability, belief and confidence in given conditional statements, and the conclusions that might be drawn.

Mental models can only represent possible world states, not attitudes or beliefs about those states. Where mental model theory has been applied to conditional reasoning, in explaining the influence of belief on thought for example, the outcome is somewhat problematic. According to mental model theory, models represent states of the world and are truth verifiable. Such models do not, therefore, include assessments of probability or belief. The idea that people form a number of mental models in response to a given problem has also

been criticised. Evidence from research into belief biases on syllogistic reasoning (Evans, Handley & Harper, 2001) suggests that people tend to form just one model, but may draw an illogical conclusion if that model is based on what is possible but not necessary.

Alternative dual process accounts of the mechanisms underlying reasoning performance suggest that there are two systems or types of processes in the brain. The interplay between these systems results in contextualised reasoning in most cases. This is not to say that reasoning on the basis of logic is not possible. Thought is not based on sets of inference rules, however, and logical thought is subject to cognitive capacity, thinking disposition and the ability to suppress interference from background knowledge.

Dual Process Theory

Dual process accounts have been applied to many areas of psychological enquiry including reasoning (Evans, 2003, 2006a; Stanovich, 1999, 2004, Klaczynski, 2000, 2001; Sloman, 1996). Dual process theories are based on the claim that there are two distinct systems for cognition (Evans, 2003). These two systems interact in complex ways to control thinking and behaviour.

Early ideas that reasoning may involve two types of thinking are reflected in work on the selection task. Wason and Evans (1975) found that although choices made on the selection task often reflected simple bias, the justifications given by participants showed no awareness of these causes. People attempted to relate choices to rational decision making in line with the instructions given. Evans (1984, 1989) developed the heuristic-analytic theory of reasoning. This theory predominantly grew out of the need to account for the growing evidence for cognitive biases in reasoning tasks. Heuristic processes provided representations of aspects of problem content along with associated knowledge and beliefs. These processes took place pre-consciously and automatically presented relevant material to the analytic system. The analytic system then generated inferences from the available information. Biases were thought to occur

where information relevant to a logical outcome was omitted, or information which was irrelevant to a logical outcome was included in activated material.

Evans and Over (1996) developed the heuristic-analytic account into dual process theory which proposed two cognitive systems in the brain. These two systems were later described by Stanovich (1999) as System 1 and System 2. At around the same time Sloman (1996) developed a dual process account identifying distinct systems for associative and rule based cognition. According to Evans and Over, System 1 is unconscious, associative and of ancient origin. This system involves fast parallel processing which is automatic and deals with pragmatic material. In contrast, System 2 is presented as slow, sequential, under conscious control and more recently evolved. This system is uniquely human and capable of logical or abstract thought.

System 1 cues pragmatic responses which are not informed by logic but are driven by innate modules or past learning. System 2 has the ability to override such responses in some cases. In terms of deductive reasoning tasks, this means that System 2 is able to derive logically correct responses if it can resist conflicting belief based responses cued by System 1. According to this theory, responding cued by System 1 is not irrational, since in everyday life it is a good idea to make decisions on the basis of all available information. Importantly, therefore, this theory suggests that it is adaptive to contextualise thinking and to reason on the basis of knowledge and belief. Contextualised reasoning was presented as rational in the sense that it is generally effective in achieving personal goals. Where rationality is equated with logic, however, reasoning on the basis of all relevant knowledge can lead to responses categorised as errors or biases.

In real life, decisions are often made on the basis of automatic or habitual responses. Evans and Over claimed that System 2 provided a different kind of thinking, one which is unique to human beings and allows us to think hypothetically about a range of possibilities. Such possibilities can be divorced from belief about real states in the world. Dual process

theory could thus account for both the ability to reason according to logical standards, but also reasoning on the basis of background knowledge and belief. This movement away from the idea that thought was intrinsically logical was mirrored by other theories, some of which had a more pronounced focus on issues relating to adaptation and the evolution of reasoning (e.g. Fiddick, Cosmides & Tooby, 2000). Such theories reject the idea that reasoning is essentially logical in favour of rationality based on evolved adaptations. Such views have been controversial. Stanovich (2004) has pointed out, for example, that the current technological environment bears little resemblance to the environment we are primarily adapted for. System 1 may reflect evolutionary rationality, but the nature of System 2 means that it can serve current goals of the individual, and in some cases override System 1 where responses are in conflict.

Typically research into dual processes has focused on competition or conflict between System 1 and System 2 processes resulting in responses which, in terms of the deductive paradigm, are categorised as errors or biases. The belief bias literature identifies a range of factors which affect people's abilities to reason logically and suppress System 1 processes based on prior belief. Dual process theory was further developed by Stanovich (1999) in identifying cognitive capacity, temperament and thinking style as important factors in an individual's ability to override System 1 influences. Stanovich (1999) refers to such influences as 'the fundamental computational bias of human cognition.' Some individuals were better able to resist the fundamental computational bias. Those with high cognitive ability were found to use prior knowledge and belief flexibly, according to its efficacy in a given situation. Stanovich and West (1998b) found that when told that a cue which is normally diagnostic, (in this case the relationship between gender and height) would not be helpful in the task given, those with higher cognitive capability were more effective in resisting belief. However, they also found that when the same cue was not presented as unhelpful, cognitive ability correlated with belief bias.

Stanovich and West (1997) demonstrate a relationship between cognitive capacity, measured via standard IQ tests, and a variety of reasoning tasks. IQ tests were significantly correlated with logical performance on all reasoning tasks. Further tests measuring the ability to override cognitive biases revealed modestly significant correlations with tests of cognitive ability. Stanovich and West concluded that the tendency to override prior belief and give logical responses when required could be predicted, to some extent, by the cognitive capacity of the individual.

In terms of dual process accounts, cognitive ability or 'g' is associated with the sequential nature of System 2, and can be described as the limiting capacity of that system. Stanovich (1999) also found, however, that once cognitive capacity is accounted for there is still a degree of variability in performance remaining. He claimed that any explanation of this additional variance should include consideration of will and disposition. Thinking dispositions are described as relatively stable mechanisms which tend to support repeated behavioural responses and strategies. Thinking style can be seen as being more malleable than cognitive ability in that it is not constrained by limited capacity. Disposition may, for example, influence the tendency to weigh evidence against a particular belief heavily, or the tendency to spend a long time considering a problem before giving up. Stanovich draws on the work of Baron (1988) in criticising the IQ concept for ignoring the influence of disposition on how people think. Baron claims that any true understanding, of thinking, must include motivational and dispositional elements, as well as cognitive capacity, in order to arrive at a full picture of the factors which lead to particular reasoning outcomes.

Stanovich and West (1998a) examined the associations between cognitive capacity, thinking dispositions and performance on a range of tasks, typically taken to demonstrate belief biases. Measures of disposition included questionnaires, designed to show levels of epistemic self-regulation. These included willingness to decontextualise, willingness to consider alternative opinions and willingness to spend more or less time on a given problem.

They found that thinking disposition scores showed significant correlations with performance on belief bias tasks after cognitive capacity had been accounted for. These findings are borne out by further work such as that of Klaczynski, Gordon and Fauth (1997) suggesting that reasoning biases which interfere with the ability to identify experimental flaws were associated with thinking style. In line with Stanovich and West, Klaczynski and Daniel (2005) found that thinking disposition predicts reasoning performance independently of verbal ability.

Although Stanovich accepts that most System 1 responses are evolutionarily adaptive, reasoners are able to arrive at outcomes which reflect either personal or rule based rationality. Reasoning which is effective in a given situation will be dependent on the cognitive resources and disposition of the individual. In everyday life, rationality reflects the goals of the individual whereas in certain situations, such as the laboratory, rationality may refer to performance on the basis of logical rules.

Recently there has been some agreement that System 1 is actually a collection of systems. (Stanovich, 2004; Evans, 2006b). What they have in common is that they all operate in response to stimuli without recourse to the cognitive capacity of System 2. Stanovich (2009) has also argued that System 2 can be divided into what he refers to as the algorithmic and the reflective minds. Higher level goal states which initiate override of System 1 reside in the reflective mind. This aspect of System 2 is related to measures of thinking style and disposition rather than measures of IQ which relate to the algorithmic mind. Crucially the algorithmic mind is concerned with hypothetical thinking and simulations which require the separation of possibilities under consideration from actual states of affairs. Such processes are effortful and depend upon the limited cognitive capacity of the system. Hence thinking style interacts with a given situation, and may cause the algorithmic mind to be initiated. This is likely to lead to an attempt to override System 1 responses. The success of override and sustained consideration of possibilities will depend on the cognitive capacity of the individual.

System 2 is generally conceptualised as concerned with explicit conscious processes which are dependent on cognitive capacity. Evans (2009) claims that a defining feature of System 2 is that it is constrained by working memory capacity. This is not to say that System 2 simply runs hypothetical simulations. Such simulations depend upon content provided by System 1. This content includes knowledge and belief about the world which are relevant to a given situation. System 2 can be seen as being characterised by a type of processing, rather than a system per se. System 2 type processes differ from System 1 type processes in that they necessarily draw upon the working memory of the individual.

Current ideas about dual process theory move away from the previous distinctions which sought to explain apparent conflict between belief and logic based responding. Previously System 1 was equated with belief based responding and System 2 was concerned with logical rule based reasoning. Recent work shows, however, that System 1 based responding can lead to logically correct outcomes and System 2 based responses can be error prone (Evans, 2007; Stanovich, 2009). If we accept Evans' definition of System 2 there is no reason why reasoning which is dependent on working memory should be decontextualised or based on rules of logic. Hence belief based reasoning can be attributed to both System 1 and System 2 (e.g. Verschueren, Schaeken & d'Ydewalle, 2005a; Weidenfield, Oberauer & Hornig, 2005). Implicit knowledge can influence behaviour directly, but knowledge and beliefs can also feed into System 2 in order to contextualise effortful reasoning processes. This is not to say that System 2 is not capable of logic based reasoning. As previously stated, in daily life the automatic contextualisation of our thoughts is adaptive and instrumental in arriving at informed decisions. In cases where decontextualised reasoning is required, however, such as mathematical study or laboratory experiments, then the inputs of System 1 may be irrelevant or unhelpful. In these cases successful performance will depend on the ability of the individual to suppress unwanted information and reason effectively.

Based on the methodology provided by Evans, Barston and Pollard (1983) a number of experimental studies have found extensive and robust evidence for the influence of background knowledge and belief on reasoning processes. Evans et al's. original experiment presented syllogisms where the conclusions were either believable or unbelievable. Results, which have subsequently been shown to be very reliable, show that people's responses are influenced by the validity of the arguments set before them, but also by how believable the conclusions are. Evidence from studies exploring the effect of content and context on reasoning performance are discussed in the next section.

Evidence for the role of knowledge and belief in reasoning: syllogistic reasoning and the selection task

The effect of both problem content and context on reasoning outcomes has been widely explored, and there is a wealth of evidence that people are highly influenced by context in a range of reasoning problems. This is the case even when participants are instructed to disregard what they know about the world and reason only on the basis of the material presented. Evidence includes belief bias in syllogistic reasoning and the facilitation of performance on Wason's selection task with content-rich, rather than abstract materials.

In terms of the deductive paradigm, belief bias is demonstrated when people respond according to belief rather than logic, even when instructed to take no account of background knowledge. The standard methodology for investigating belief bias was introduced by Evans et al. (1983). Four categories of syllogisms were presented allowing for comparisons of situations where belief and logic were either *in concert*, or *in conflict*. Syllogisms were either valid or invalid and had conclusions which were either believable or not believable. Hence the four categories were valid/believable, invalid/believable valid/unbelievable,

invalid/unbelievable. For example, participants were presented with the following valid/unbelievable syllogism, where belief and logic were in conflict:

No nutritional things are inexpensive
Some vitamin tablets are inexpensive
Therefore, some vitamin tablets are not nutritional

The form of this argument is logically valid but the conclusion is contrary to what most people believe about vitamins. Evans et al. (1983) instructed participants to reason according to logic on the basis only of the premises presented. The results showed, however, that participants were consistently influenced by the believability of the conclusion, as well as the validity of the arguments. Evans et al. concluded that people attempt to follow the instructions and reason logically, but find it very difficult to suppress contextual information about what they believe to be true.

Experimental evidence of belief bias has been instrumental in undermining logicist accounts of reasoning. The effect has been demonstrated in a wide number of studies (e.g. Klauer, Musch & Naumer, 2000; Morley, Evans & Handley, 2004; Newstead, Pollard, Evans & Allen, 1992) and repeatedly shows that people are highly influenced by content and context when engaged in reasoning. It is important to recognise that the influence of knowledge and belief can both impede and facilitate logical performance. Belief bias in syllogistic reasoning demonstrates that where logic and belief are in conflict, responding in line with logic is less likely. Other evidence from Wason's selection task has focused on the ways in which context can facilitate logical outcomes.

There have been a large number of studies demonstrating context effects on Wason's selection task (See Manktelow, 1999; Evans & Over, 2004, Chapter 5, for reviews). As we have seen, the abstract version of this task is very difficult even for educated adults. Wason's confirmation bias account of performance on the abstract version of the task has since been superseded by explanations based on a simple matching bias (Evans & Lynch, 1973). Some

studies suggest that people with very high intelligence are able to avoid matching bias and identify the correct cards (Stanovich and West 1998a). Most people are unable to reason logically on the task, and base their analysis of the problem only on the cards which match those named in the rule. Early manipulations of the problem showed, however, that the problem was much easier to solve when it was presented in a realistic context (Wason & Shapiro, 1971). A standard abstract version was compared with a version with familiar content. In this case the rule 'Every time I go to Manchester I travel by train' was presented along with the following four card selection:

Manchester Leeds Train Car

As in the standard task participants were asked to decide those cards, and only those cards, that need to be turned over in order to discover whether the rule is true or false. Significantly more correct card choices were made in the realistic, compared to the abstract version.

Subsequent studies found that facilitative versions of the task with realistic content differed from standard abstract versions, as they tended to express permission rules or obligations (See Evans & Over, 2004, Chapter 5, for a review). This deontic version of the selection task generally required participants to identify where a rule had been violated. Participants are likely to choose the correct cards if they are familiar with the content, or the rationale behind it as a rule governing people's actions. Facilitation is also improved by the inclusion of a minimal contextual scenario. One particularly well used example is the drinking age problem (Griggs & Cox, 1982). Participants are told to imagine they are police officers observing people's drinking behaviour in a bar, to check if the following rule is being obeyed:

If a person is drinking beer, then that person must be over 19 years of age

The four cards presented are as follows:

Drinking beer Drinking coke 21 years of age 16 years of age

Griggs and Cox found that around 75% of participants chose the logically correct 'Drinking beer' and '16 years of age' cards. A later study (Pollard & Evans, 1987) found that removal of

the provided context (the police officer role) reduced correct card choices to a similar level to a control task with abstract content.

There are many different theoretical accounts of the facilitation provided by context in the deontic selection task (e.g. Cosmides, 1989; Pollard, 1982; Cheng & Holyoak, 1985; Sperber, Cara & Girotto, 1995). What is of importance in relation to the studies presented here is that reasoning outcomes are influenced by the presentation of realistic content and contextual framing. In this case context enhances logical performance. This is not to imply that context encourages logical reasoning processes, however. Unlike the abstract version of the task there is evidence that performance is not highly related to IQ (Stanovich & West 1998c), suggesting it may rely to a greater extent on heuristic processes. Evans and Over (2004) suggest that the deontic task is easy simply because the context cues automatic attention to relevant cases.

The studies presented in this thesis are concerned with conditional reasoning with everyday content. Most of the work on belief in reasoning has focused on the influence of background knowledge in terms of biases, as we have seen with syllogistic reasoning and the selection task. It is not a bias, however, to reason on the basis of what we know to be true in everyday situations. In fact the kind of contextualised reasoning we typically employ in our daily lives is adaptive, and helps us to achieve goals and think flexibly. Nevertheless, investigations of the role of knowledge in conditional reasoning have tended to rely on the deductive paradigm.

Conditional reasoning with everyday content and its development

Studies of conditional reasoning have tended to focus on the conditional inference task involving presentation of a major premise of the form 'if p then q' and the four possible minor premises described in section 1. (MP, MT, AC and DA). In the valid arguments, MP and MT, the conclusion necessarily follows from the premises. In the case of the invalid inferences, AC and DA, the conclusion does not necessarily follow given the premises. Instructions in standard conditional inference tasks generally ask the participant to assume the

premises are true and decide if a conclusion necessarily follows from the premises given.

There have been a number of studies exploring conditional inference with abstract materials (See Evans & Over, 2004, for a review). Although findings are somewhat mixed, in relation to the invalid inferences in particular, for our purposes it is important to know that MP tends to be very readily drawn compared to other inferences and there is a tendency for people to respond with certainty to the invalid inferences. For example, in response to the following premises of an AC argument:

If there is a 3, then there is an A

There is an A

People tend to conclude that there is a 3 even though it does not logically follow that this is necessarily the case.

Studies of conditional reasoning with everyday content have also tended to use the deduction paradigm. As with abstract content participants are often instructed to assume the premises are true and say whether conclusions necessarily follow. As we have seen this paradigm defines contextual effects as biases and errors which is arguably inappropriate when investigating the influence of relevant knowledge on the kind of reasoning we employ in our daily lives. Some studies of conditional reasoning have used pragmatic instructions where participants are not asked to assume the truth of the premises but just invited to say what they think will follow. Some tasks also ask participants to express how likely or probable a conclusion might be.

Everyday conditional reasoning performance has been repeatedly shown to be influenced by background knowledge in both older children (Janveau-Brennan & Markovits, 1999) and adults (e.g., Cummins, 1995; Cummins, Lubart, Alksnis, & Rist, 1991; Thompson, 1994). Context in the form of disabling conditions and alternative antecedents, collectively known as counterexamples, have been shown to influence the tendency to endorse both valid and

invalid conclusions (e.g. Cummins, 1995; Cummins et al., 1991; Quinn & Markovits, 1998; Thompson, 1994).

In standard logic, MP is considered to be a valid inference, in that there is only a single logically correct conclusion. Consider the following example:

If Mary goes shopping, then she buys some fruit.

Mary goes shopping

Therefore, it follows that Mary buys some fruit.

AC, on the other hand, is considered to be invalid, the logically correct answer being one of uncertainty. However, research suggests that people tend to respond with certainty to invalid inferences and consequently commonly endorse AC. Consider the following example:

If Mary goes shopping, then she buys some fruit.

Mary buys some fruit

The logically correct conclusion here is one of uncertainty, hence logically we should conclude that Mary may or may not have gone shopping. People typically endorse AC however, in which case they conclude:

Therefore, it follows that Mary went shopping.

Importantly, the tendency to make each inference is related to any prior knowledge and belief the participant holds about the content. In particular, such inferences may be blocked by prior knowledge of counterexamples which are of two kinds. A *disabling condition* is a case where the antecedent clause may not lead to the consequent. For example, if we imagine that there is no fruit available in the market where Mary goes shopping, then she will not be able to buy any. If people consider such disabling conditions they are less likely to draw the valid inferences, MP and MT. An *alternative antecedent* is a case which allows the consequent to occur without the antecedent. For example, Mary may have fruit delivered to her house, so that she does not need to go shopping. Considering alternative antecedents or causes leads to fewer endorsements of the invalid inferences AC and DA.

Background knowledge and belief can, therefore, influence the responses people give to conditional reasoning problems in a systematic way. Where disabling conditions are available people tend to withhold the logically correct response to valid inferences. On the other hand, where alternative antecedents are available logical performance on invalid inferences is enhanced. The influence of context on conditional reasoning is, therefore, distinct from logical reasoning ability, since the impact of knowledge on valid and invalid inferences acts both to suppress and facilitate logical reasoning.

The influence of background knowledge on conditional reasoning is subject to development (Janveau- Brennan & Markovits, 1999; Klaczynski, Schuneman & Daniel, 2004; Markovits & Thompson, 2008; Muller, Overton & Reene, 2001) and in children, at least, involves effortful processes (Morsanyi & Handley, 2008). Although children as young as 4 years of age can draw valid inferences (Dias & Harris, 1990; Markovits, 2000), very young children show little effect of background knowledge (Markovits & Barrouillet, 2002). Contextualised reasoning, among typically developing youngsters, develops through late childhood into adolescence. There are a number of reasons why this is the case (Markovits & Barrouillet, 2002; Markovits, Fleury, Quinn & Venet, 1998; Markovits & Thompson, 2008). Young children simply have less background knowledge available in long term memory. Retrieval of information is less efficient in younger children, compared to adolescents. The strength of association between the presented material and available knowledge is also likely to affect performance. Critically, children's contextualized reasoning performance is related to the cognitive demands of representational processes. Reasoning on the basis of all relevant information involves the creation of complex relational schemas which integrate information about the presented material with background knowledge in the form of counterexamples. Young children are limited in the complexity of such schemas they are capable of forming, and for very young children reasoning relies predominantly on the consideration of the major premise presented (Markovits and Barrouillet, 2002).

Children tend to interpret inferences biconditionally (if and only if p then q) and consequently tend to respond with certainty to AC (Markovits, 2000; Markovits, Venet, Janveau-Brennan, Malfait, Pion, & Vadeboncoeur, 1996). The ability to respond with uncertainty to invalid inferences does not reliably appear until adolescence (Muller et al., 2001). At around age 8 children are beginning to produce uncertainty responses to AC (but not DA). At around this point children also begin explicitly to state disabling conditions as justifications and some children begin to show evidence of denial of MP. Not until around 11 years are children able to respond with uncertainty to DA, this is accompanied by relatively high reference to counterexamples as justifications and denial of MP in some cases. Once children can respond with uncertainty to AC and DA their responses vary according to whether there are few or many available alternatives (Janveau-Brennan & Markovits, 1999).

Developmental factors seem to specifically impact on the cognitively demanding consideration of counterexamples in conditional reasoning. Typically developing 6 year olds appear able, for example, to make probabilistic judgments about conditional statements, as they can state how believable a statement is. They find it difficult, however, to draw on background knowledge when engaged in conditional inference tasks, even when such information is actively presented (Markovits and Thompson, 2008). As adolescents move towards adulthood the development of inhibitory and meta-cognitive processes allows for more control over reasoning, and a more selective use of background knowledge (Markovits & Barrouillet, 2002; 2004; Muller et al., 2001). Typically developing adolescents, therefore, present a population which is arguably more influenced by background knowledge compared to younger children and adults.

Conclusion

Forty years of research into deductive reasoning has clearly demonstrated that people are highly influenced by the content and context of the problems presented (Evans, 2002). In deductive reasoning tasks people are usually required to assess the logical nature of arguments or arrive at logical conclusions. The evidence shows, however, that people find it very hard to ignore what they know about the world. This is particularly true of children. Typically developing adolescents, may also lack inhibitory and metacognitive skills necessary to selectively ignore their own beliefs, compared to adults. These effects are typically referred to as a cause of 'cognitive bias', since participants are routinely instructed to draw only necessary conclusions based on the information given, rather than background knowledge. This perspective reflects the logicist origins of the deductive paradigm not the nature of the kind of reasoning we use in our daily lives. The ability to take account of background knowledge and belief in everyday reasoning is highly adaptive, and contextualised reasoning is rational in the sense that it is generally effective in achieving personal goals (Evans, 2007). Where rationality is equated with logic, however, reasoning on the basis of all relevant knowledge can lead to responses categorised as errors or biases.

Implicit and explicit processes can be informed by prior knowledge and belief hence belief based reasoning can be attributed to both System 1 and System 2. Implicit knowledge can influence behaviour directly, but knowledge and beliefs can also act to contextualise System 2 reasoning processes. Effortful reasoning performance is constrained by individual differences, specifically cognitive capacity. The ability to override prior belief is predicted, to some extent, by differences in IQ. Further variance is also explained by individual thinking dispositions which direct, for example, the willingness to consider options or spend time considering a problem.

The impact of content and context on reasoning has been demonstrated on a range of tasks including syllogistic and conditional reasoning. In the case of everyday conditional

reasoning background knowledge can influence the conclusions people draw through the activation of specific exceptions available in long term memory, and the integration of such counterexamples with presented stimuli. In the next chapter we will explore the influence of knowledge and belief on everyday conditional reasoning among adolescents with ASD compared with a typically developing control group.

Chapter 3

Introduction

As discussed in the previous chapter, four decades of research into deductive reasoning has shown that participants are highly influenced by the context and content of given problems (Evans, 2002). This has been demonstrated with a range of reasoning tasks including those involving syllogistic reasoning, variants of Wason's selection task and conditional reasoning problems. Such effects are typically referred to as cognitive biases, as participants are usually instructed to draw conclusions based only on the information provided. This perspective is derived from the deductive paradigm, however, and is arguably inappropriate when considering conditional reasoning with everyday content, where the integration of background is highly adaptive and helpful in negotiating through life (Evans, 2007). Although much is known about contextualized reasoning among typical populations, very little is known about the effects of content and context on the reasoning of individuals with autism spectrum disorders (ASD).

In this chapter I will discuss available evidence about the reasoning abilities of individuals with ASD and explore what might be expected in terms of contextualized reasoning within this population. I will then present the findings of a study exploring the influence of background knowledge and belief on everyday conditional reasoning among adolescents with ASD and a typically developing control group.

Adolescents were chosen as fitting participants for this study as the effect of background knowledge on reasoning outcomes is particularly marked in typically developing adolescents compared to younger children and adults. There are a number of reasons for this. Younger children, for example, do not have the same knowledge available as older children and adults and their retrieval skills are less well developed (e.g. Markovits, Fleury, Quinn & Venet, 1998; Markovits & Thompson, 2008). As children move into adolescence their reasoning becomes

highly influenced by the background knowledge available. This is partly due to a more extensive knowledge base and effective retrieval of information but also because they lack the inhibitory and meta-cognitive processes available to adults, which allow for more control over reasoning and a more selective use of contextual information (Markovits & Barrouillet, 2002; 2004; Muller et al. 2001).

Current knowledge about contextual effects and the integration of information in reasoning among individuals with ASD is limited. Studies that exist tend to focus on reasoning with contrary-to-fact or counterfactual material and reasoning with embedded rules.

Two conflicting studies have explored the ability of children with ASD to solve contrary-to-fact reasoning problems. Scott, Baron-Cohen and Leslie (1999) presented children with ASD, children with mild learning difficulties (MLD), and typical controls with contrary-to-fact reasoning problems, either with or without direct prompts to consider an imaginary context. In the imaginary condition, children were prompted, through a number of questions to imagine aspects of the scenario. For example, all participants were told to assume the premises were true and were presented with contrary-to-fact problems as follows:

All pigs can fly

John is a pig

Can John fly?

In the imaginary condition participants were also given seven questions to prompt consideration of the imaginary context. For example:

Can you make a picture of the pig in your head?

Can you make the pig do something different or funny?

Scott et al. found the children with ASD performed well on contrary-to-fact tasks with no prompts to consider the context, but poorly where cues to use imagination were provided. This was in contrast to both typically developing controls and children with moderate learning difficulties. Both of these groups showed improved performance when prompted to use

imagination. One explanation given was that the participants with ASD were not hindered by the drive to integrate presented material with background knowledge in the contrary-to-fact only task. Where they were required to take account of the imaginary context this lack of integration meant that the typical facilitation of context was not demonstrated. These findings have been called into question, however, by a subsequent study (Leevers & Harris, 2000) which found children with ASD performed at around chance levels on contrary-to-fact reasoning tasks and showed a strong positive response bias.

Further relevant studies have tended to focus on counterfactual and rule-based reasoning relating to Theory of Mind tasks. Impairments on Theory of Mind tasks have been explained in terms of reasoning ability. Cognitive Complexity and Control Theory (Zelazo & Frye, 1997; 1998; Zelazo, Jaques, Burack & Frye, 2002) suggests that performance on false belief tasks relies on using higher order, 'if-if-then' rules which have the form 'if setting 1, then if x then y'. In Theory of Mind tasks, setting conditions refer to the viewpoint of either self or other character. In the Sponge-rock task (Flavell, Flavell & Green, 1983), for example, the child knows an object resembling a rock is actually a sponge. They are asked what their friend will think the object is. This involves reasoning with the following if-if-then rule (Frye, Zelazo & Burack, 1998):

If Friend, then if this object, then rock.

Setting conditions allow the integration of two perspectives into a single system of inferences through the creation of complex relational representations. Very young typically developing children and individuals with ASD have difficulties reasoning with embedded rules (Frye, Zelazo & Palfai, 1995; Zelazo et al., 2002).

Reassessments of false belief tasks have also led to the suggestion that children with ASD fail false belief tasks because of their inability to reason counterfactually. The implication is that the ability to reason about a state of affairs taking account of one's own beliefs and those of another person requires counterfactual reasoning with embedded 'If-if-then' rules. These

difficulties are particularly apparent in tasks such as the standard false belief task where inferences must be drawn but critical information is not made explicit and has to be gleaned from a given context (Peterson & Riggs, 1999; Riggs & Peterson, 2000). Grant, Riggs and Boucher (2004) found that children with ASD were able to solve non-standard false belief tasks which did not involve counterfactual reasoning but performed poorly on physical state counterfactual reasoning problems which did not involve the understanding of belief.

Information about conditional reasoning among individuals with ASD is minimal but one recent study (Pijnacker et al., 2009) explored the ability of high functioning adults with autism to revise conditional reasoning conclusions on the basis of new contextual information. This study is discussed in more detail in Chapter 4. Findings suggest that the presentation of extra contextual information influences reasoning outcomes for typical controls to a greater extent than for adults with ASD. This study in conjunction with the studies exploring counterfactual reasoning and reasoning with embedded rules do indicate, therefore, that individuals with ASD may have difficulties with integrating perspectives, or drawing inferences on the basis of a given context.

In addition to what is suggested by existing studies of reasoning among individuals with ASD, the information processing style associated with autism implies that their reasoning may differ from that of typical groups in significant ways. A number of current theories about autism including *Weak Central Coherence Theory*, *Underconnectivity Theory*, and the *Complex Processing Deficit* account explore the difficulties people with ASD may have with contextualizing or integrating information. *Weak Central Coherence Theory* (Frith, 1989; 2003; Happé & Booth, 2008; Happé & Frith, 2006) proposes that human beings have an inherent drive towards central coherence, the formation of coherent wholes through the integration of pieces of relevant information. Incoming stimuli tend to be processed in context to derive a meaningful gist of the situation, often at the expense of surface details. Frith claims that individuals with ASD differ from the typical population in exhibiting a

tendency towards weak central coherence which results in an over reliance on local or piecemeal processing, and a tendency not to integrate information in order to process stimuli in context.

The tendency towards weak central coherence in populations with ASD has been demonstrated across a number of domains. This processing style has been shown to result in poor performance on tasks which require the integration of presented material with background information to arrive at higher meaning. Evidence includes poor performance in the disambiguation of homographs (Frith & Snowling, 1983; Jolliffe & Baron-Cohen, 1999a) and the interpretation of words in ambiguous sentences (Jolliffe & Baron-Cohen, 1999b).

On the basis of what is known about reasoning and information processing among individuals with autism it is reasonable to predict that individuals with ASD may be less influenced by background knowledge in everyday conditional reasoning compared to a typical control group.

Much is already known about the influence of prior knowledge on everyday conditional reasoning tasks among the typical population (Evans, 2007; Evans & Over, 2004). Conditional reasoning performance is influenced by background knowledge in both older children (Markovits & Janveau-Brennan, 1999) and adults (e.g., Cummins, 1995; Cummins, Lubart, Alksnis, & Rist, 1991; Thompson, 1994). Knowledge can impact on conditional reasoning in different ways (Verschuere, Schaeken & d'Ydewalle, 2005), through the automatic activation of associations reflecting belief in the conclusion presented, or through the activation of specific exceptions available in long term memory, and the integration of this information with presented stimuli.

The study presented here is based on that of Cummins et al. (1991) we will, therefore, consider this work in some detail. Cummins et al. were interested in the effect of two specific types of background knowledge on conditional reasoning outcomes, alternative antecedents

and disabling conditions. Alternative antecedents are alternative causes which can lead to a stated effect. For example if we consider the following statement:

If Marie eats sweets often, then she will have fillings

If we are then told that Marie does have fillings and asked if it follows that she eats sweets often, we may bring to mind alternative reasons why Marie may have fillings. We may consider the possibility, for example, that Marie often eats cakes or drinks sugary drinks. Disabling conditions are conditions where the effect does not follow from the cause. Hence if we are told that Marie does eat sweets often, and asked if it follows that she has fillings, we may bring to mind situations where eating sweets may not lead to fillings. We may consider, for example, that Marie might have strong enamel or be very careful about dental hygiene.

Alternative antecedents and disabling conditions are collectively known as counterexamples. In the Cummins et al. (1991) study a number of conditionals were pretested in order to establish whether they had high or low numbers of available counterexamples. They did this by presenting participants with rules and facts and asking them to generate either alternatives or disablers as in the following example for the generation of alternative antecedents:

Rule: *If Marie eats sweets often, then she will have fillings*

Fact: *Marie has fillings, but she doesn't eat sweets often*

Please write down as many circumstances as you can that could make this situation possible

The conditionals were then classified as having either high or low numbers of available counterexamples and presented to a new group of participants in a conditional inference task. What Cummins et al. and many subsequent studies found was that for conditionals where many disabling conditions were available the endorsement of conclusions for valid inferences was significantly lower than where there were few disabling conditions available. Where high numbers of available antecedents were available participants also drew fewer invalid inferences.

The task used here will focus on two main conditional inference patterns, Modus Ponens (MP) and Affirmation of the Consequent (AC). Conditional reasoning involves inference with a major premise of the form 'if p then q'. In the case of MP this involves reasoning from the premises 'if p then q, p is true,' this leads logically to the response 'p is true.' MP is a valid inference in that there is a single logically correct response. AC requires reasoning with the premises 'if p then q, q is true. AC is an invalid inference in the sense that the correct logical response is one of uncertainty. Here the implied response is not logically correct, although there is a tendency for people to respond with certainty by giving the pragmatically implied conclusion 'p is true.'

It has been claimed that willingness to endorse arguments is influenced by the extent to which knowledge about counterexamples is activated and integrated with presented material. Consider the following example of a MP argument (Markovits & Potvin, 2001).

If a chair is thrown at a window, then the window will break

Suppose a chair is thrown at the window, does it follow that the window is broken?

Whilst the conclusion follows logically in this case, many participants will withhold the inference because there are many available disabling conditions. They may think of specific situations where the effect does not follow from the cause (e.g. the window is made of toughened glass or the chair is made of plastic etc.). The activation and integration of such disablers increases the tendency for people to withhold the inference.

Similarly if we consider the invalid AC form:

Suppose the window is broken, does it follow that a chair was thrown at the window?

Whilst reasoners often endorse the AC conclusion, in this example there are many counterexamples in the form of alternative antecedents or causes which would lead to the same effect (such as throwing a rock or a cricket ball at the window). In the case of invalid inferences, where alternatives are available, people are more likely to give the correct logical 'uncertainty' response to this argument form. The influence of context on conditional

reasoning is, therefore, distinct from logical reasoning ability, since the impact of knowledge on valid and invalid inferences acts both to suppress and facilitate logical reasoning.

This account assumes that specific counterexamples are activated and integrated with premise information. Background knowledge can either act to discourage the endorsement of logically valid inferences or, in the case of invalid inferences, act to support logical responses based on uncertainty. This finding has been shown to be robust in typical adolescent and adult populations and has been demonstrated in a number of studies (e.g. Markovits & Janveau-Brennan, 1999; Cummins, 1995; Thompson, 1994).

It was predicted that difficulties with integrating information and impairment in contextualized thinking would result in atypical conditional reasoning performance, with regard to the influence of available counterexamples, among adolescents with ASD. In Experiment 1 the availability of disablers and alternative antecedents was manipulated on conditional reasoning problems. It was predicted that the typically developing adolescents would be influenced by the availability of disabling conditions in their responses to MP inferences, and by the availability of alternative causes in their responses to AC inferences. In the case of the adolescents with ASD, however, they would be less influenced by the availability of counterexamples in their responses to MP and AC. Since counterexamples have been shown to suppress and facilitate logical reasoning performance for valid and invalid inferences respectively, we presented both types of inference. The inclusion of both valid and invalid inferences allowed us to examine the effect of context on reasoning ability controlling for any group differences in logical reasoning ability. In addition, a probability judgment task was included, which allowed us to measure the relevant associative beliefs, concerning the relation expressed in each conditional statement, in order to ensure that any differential effects of counterexamples between the two groups could not be attributed to differences in underlying beliefs.

Pretest

Forty questions were largely drawn from Cummins et al. (1991). In this study conditional statements were used that described causal relationships. These statements varied in the number of alternative antecedents and disabling conditions available, relating to the causal relationship. Since this study used typical adult participants, for the purposes of the pretest some additional questions were adapted for a younger audience. The children included in the pretest were all recruited from a mainstream school in the Plymouth area of Southern England with a lower middle class catchment profile. This school was also used to recruit adolescents with ASD in Experiments 1, 2 and 3. As such, the pretest group was deemed to be from similar educational and socioeconomic backgrounds as subsequent participants. The pretest group included typically developing adolescents with a range of educational abilities. Any child with a diagnosis for autism or Asperger syndrome or a statement of special educational needs was excluded from the pretest group. The children were recruited from the youngest age range included in subsequent experiments, and were between 11 and 12 years of age. This age group was chosen as the developmental literature suggests that children of around 11 years are only just beginning to reliably demonstrate the influence of disabling conditions and alternative causes on reasoning performance. A number of factors relate to contextualized reasoning ability in typically developing youngsters, particularly in the younger age brackets. These include the strength of association between background knowledge and associated material, and the knowledge that is available for retrieval in long term memory (Markovits & Janveau-Brennan, 1999). The purpose of the pretest was to categorise materials for use in later experiments as having either low or high available counterexamples. It was necessary, therefore, to ensure that the youngest children in the subsequent experiments would be sensitive to differences in availability of counterexamples.

The questions were piloted with forty typically developing adolescents in four groups of ten in order to establish four groups of statements with:

- High numbers of disabling conditions and high numbers of alternative antecedents, for example:
If a mug is dropped, then it will break.
- High numbers of disabling conditions and low numbers of alternative antecedents, for example:
If the trigger is pulled, then the gun will fire.
- Low numbers of disabling conditions and high numbers of alternative antecedents, for example:
If a balloon is pricked, then it will burst.
- Low numbers of disabling conditions and low numbers of alternative antecedents, for example:
If butter is heated, then it will melt.

Each group of 10 children was presented with 10 MP and 10 AC conditionals. The children were asked to generate as many counterexamples as possible, for each question, in one and a half minutes. Mean numbers of alternatives and disablers were calculated for each conditional. These means were split into quartiles, and 4 groups of 4 conditionals chosen, which best fitted the required high-low categories. Mean numbers of alternatives and disablers for each of the 4 categories listed above are shown in Table 3.1.

Table 3.1. Mean numbers of alternative antecedents and disabling conditions generated in the pretest for each high-low category.

High - low categories	Mean counterexamples generated	
	Alternatives	Disablers
Low alternatives – low disablers	0.30	0.55
Low alternatives – high disablers	0.55	2.15
High alternatives – low disablers	2.73	0.98
High alternatives – high disablers	2.35	2.35

Experiment 1

Experiment 1 examined conditional reasoning and probabilistic judgments in relation to available counterexamples. In this experiment adolescents with ASD and a control group of typically developing adolescents were tested. Both groups performed a conditional reasoning task, where statements had varying available disabling conditions and alternative antecedents, followed by a likelihood judgment task. In the second task participants were asked to rate the believability of the statements presented.

Method

Participants

Participants included 26 adolescents with ASD and 38 typically developing adolescents. The adolescents with ASD were between the ages of 11 and 16 years. The typically developing adolescents were between the ages of 11 and 15. None of the participants had previously taken part in the pretest. Participants were recruited by approaching mainstream schools

known to have special units supporting pupils on the autistic spectrum. In the group with ASD only those adolescents were included who had a definitive clinical diagnosis of autism spectrum disorder meeting criteria from the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.; DSM-IV; American Psychiatric Association, 1994) or *International Classification of Diseases* (10th ed; ICD-10; World Health Organization, 1993). Diagnoses were carried out by either a paediatrician or child and adolescent psychiatrist following multidisciplinary assessment. Adolescents with ASD with either a medical diagnosis such as epilepsy or a neurodevelopmental diagnosis other than autism such as attention deficit hyperactivity disorder, or who were taking medication, were excluded from the study. There were 21 boys and 5 girls in the group with ASD. There were 23 boys and 15 girls in the typically developing group. There were 22 high functioning adolescents diagnosed as having ASD or autism and 4 adolescents diagnosed with Asperger syndrome. Within the typically developing group children were excluded if they had a diagnosis of ASD, Asperger syndrome or were documented as having autistic traits. Children who had a statement of special educational needs were also excluded.

Typically developing and autistic participants were recruited from the same mainstream schools in lower middle class urban areas within Plymouth and West Devon. All of the teenagers who took part in the study were white, predominantly lived in urban areas and English was the first language for all of the participants.

All participants were given a range of tests measuring participant characteristics, including a non verbal working memory task (adapted from Wilson, Bettger, Nicolae & Klima, 1997). Our task differed from that of Wilson et al. in that it included processing and storage elements. Participants had to recall, in sequence, the location of a series of blocks. In addition to the span task, participants were also required to recall the final location of the previous trial sequences. Scores represent, therefore, a measure of the ability to process and store given information. Working memory was measured as it has been shown to be highly correlated

with general intelligence (Colom, Rebollo, Palacios, Juan-Espinosa & Kyllonen, 2004) and reasoning ability (Kyllonen & Christal, 1990).

Participants were also given The Stop-Signal Task (Logan, Schachar, & Tannock, 1997), taken to measure inhibition. A measure of inhibition was included since inhibitory processes are proposed to mediate reasoning performance through individual differences in the selective suppression of competing responses (De Neys et al. 2005). The Stop-Signal Task requires participants to suppress a prepotent response (pressing a button in response to a tone). Scores represent the overall number of correct responses to stop signal trials across a number of different time delays between the presentation of the tone and the stimuli.

The expressive vocabulary test of The Wechsler Intelligence Test for Children (WISC-III, Wechsler, 1991) was also given to all participants. The WISC expressive vocabulary test was chosen as it was felt to be of importance that the two groups were comparable on their ability to understand the terms used within the given problems. This subtest measures verbal concept formation, fund of knowledge and degree of language development.

Adolescents were excluded from both typical and autistic participation groups if they scored either two standard deviations above or below the mean scaled score for their age group on the WISC expressive vocabulary measure. Scores above or below these points were deemed unacceptable as they reflected unusually high or low ability for any given age range. Excluded individuals had scores which were the same as, higher than 2% of a given age range or lower than 2% of a given age range. Participants were also excluded if they failed to score on either the storage or processing elements of the working memory task.

Adolescents with ASD were matched as closely as possible with the typically developing adolescents on the basis of the individual differences measures and chronological age (See Table 3.2). No significant differences between the two groups were found for chronological age ($t(62) = 1.07$ $p = .29$), age corrected standard vocabulary scores ($t(62) = -1.02$ $p = .31$), working memory span ($t(62) = -0.44$ $p = .66$), or inhibition ($t(62) = -0.81$ $p = .42$).

Table 3.2. Measures of participant characteristics for the typical group and the group with ASD in Experiment 1

	Autistic			Typical			Differences between groups
	Range	Mean	SD	Range	Mean	SD	<i>p</i>
Chronological Age (Months)	133-203	168.08	19.43	143-188	163.61	14.90	.29
Standardised Vocabulary scores	4-13	8.65	2.98	4-16	9.42	2.96	.31
Working Memory Span	0.5-4.5	2.19	1.13	0.5-4.0	2.08	0.91	.66
Inhibition	6-62	38.55	13.03	10-57	41.21	10.28	.42

Materials and procedure

Conditional reasoning task

There were 32 questions in the reasoning task, 16 MP and 16 AC statements, four from each of the pretest high-low categories (See Appendix A1). Hence for half of the questions the correct logical response was 'Yes, definitely' and for the other half, 'No, not necessarily.' The task was presented by an animated robot on a computer screen. As the purpose of the study was to explore the effect of background knowledge on reasoning processes, participants were presented with brief pragmatic instructions as follows:

In this task you will be shown some statements. After each statement there will be a fact and a conclusion. Given the statement and the fact, you need to make a decision about whether the conclusion follows.

The Participants were then presented with two practice questions, one of each inference type. Feedback was given to ensure that participants understood the task. The experimental statements were then presented in a random order. Questions remained on the screen until the participant responded. All questions were presented as a statement, an invitation to suppose a fact, and a question about what follows:

If the ignition key is turned, then the car will start

Suppose that the ignition key is turned,

Does it follow that the car will start?

Participants were required to respond by pressing one of two buttons, labelled **'YES, definitely'** and **'NO, not necessarily.'** The correct logical responses for MP questions being 'yes, definitely' and for AC being 'No, not necessarily.'

Probability judgment task

Participants were presented with the 16 conditionals used in the inference part of the study and asked to rate the likelihood of the consequent in the light of the antecedent. The conditionals either expressed forward causality (if cause then effect, $P(q|p)$) or backward causality (if effect then cause, $P(p|q)$), the probability judgments relevant to the MP and AC inferences respectively, giving a total of 32 questions. The task was presented on a computer screen by the same animated robot used in the conditional reasoning task. Participants were given the following instructions:

On the following screens you will see some statements. You will be asked how likely each statement is. You will have to rate how likely the event is by clicking a number from 1 to 5.

Participants were then shown an example question and the scale was explained to them. They were told that clicking on number one meant 'not very likely' and five meant 'very likely'. The statements were then presented in a random order. Questions remained on the screen until the participant responded. The participants were given two practice questions where the scale was explained by the robot character again and visual reminders of the values represented by the scale were shown. All questions were presented in the following format:

How likely is it that

If a towel is dropped in the bath, then it will get wet?

Not likely 1 2 3 4 5 Very likely

Results

Conditional reasoning task

A 2 (group) by 2 (low vs high disablers) repeated measures Anova was performed on the MP inference data from the conditional reasoning task. Mean endorsement responses for MP questions, comparing autistic and typical groups are shown in Figure 1. The analysis revealed a main effect of disablers ($F(1,62) = 5.82, MSE = 1.16, p = .02, \eta^2_p = .09$) and a significant two-way interaction between disablers and group ($F(1,62) = 6.81, MSE = 1.16, p = .01, \eta^2_p = .10$), such that disablers affected the reasoning of the typical adolescents more than the adolescents with ASD (See Figure 3.1).

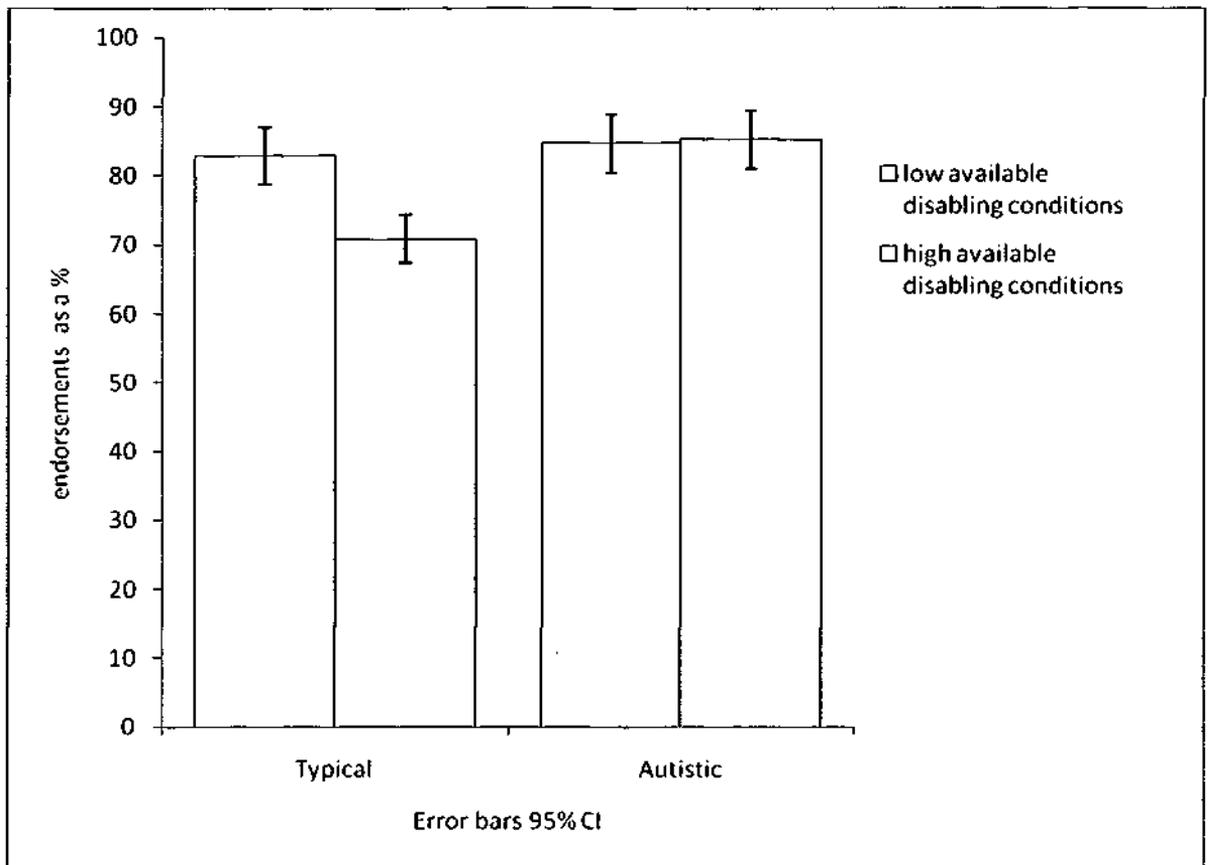


Figure 3.1. Mean number of endorsement responses as a percentage for MP questions with low and high available disablers by the autistic and typical groups.

In order to provide further information about the interaction between group and disablers, we performed paired sample t tests to test for an effect of disablers in each group. These showed a significant difference in endorsement rates on MP between high and low disabler questions among the typically developing group ($t(37) = -3.35$ $p = .002$) but no significant difference in endorsement rates among the group with ASD ($t(25) = -0.20$ $p = .85$).

A second Anova was performed to examine the effect of alternatives (high vs. low) on AC inferences, with autism as a between subjects factor. Mean endorsement responses for AC questions, comparing autistic and typical groups are shown in Figure 2. The analysis revealed a main effect of alternatives ($F(1,62) = 34.31$, $MSE = 2.74$, $p < .001$ $\eta^2_p = .36$). Again, the predicted significant two-way interaction was found between alternatives and group ($F(1,62) =$

8.34, $MSE = 2.74$, $p = .01$ $\eta^2_p = .12$), reflecting greater use of alternatives in the typically developing group (see Figure 3.2).

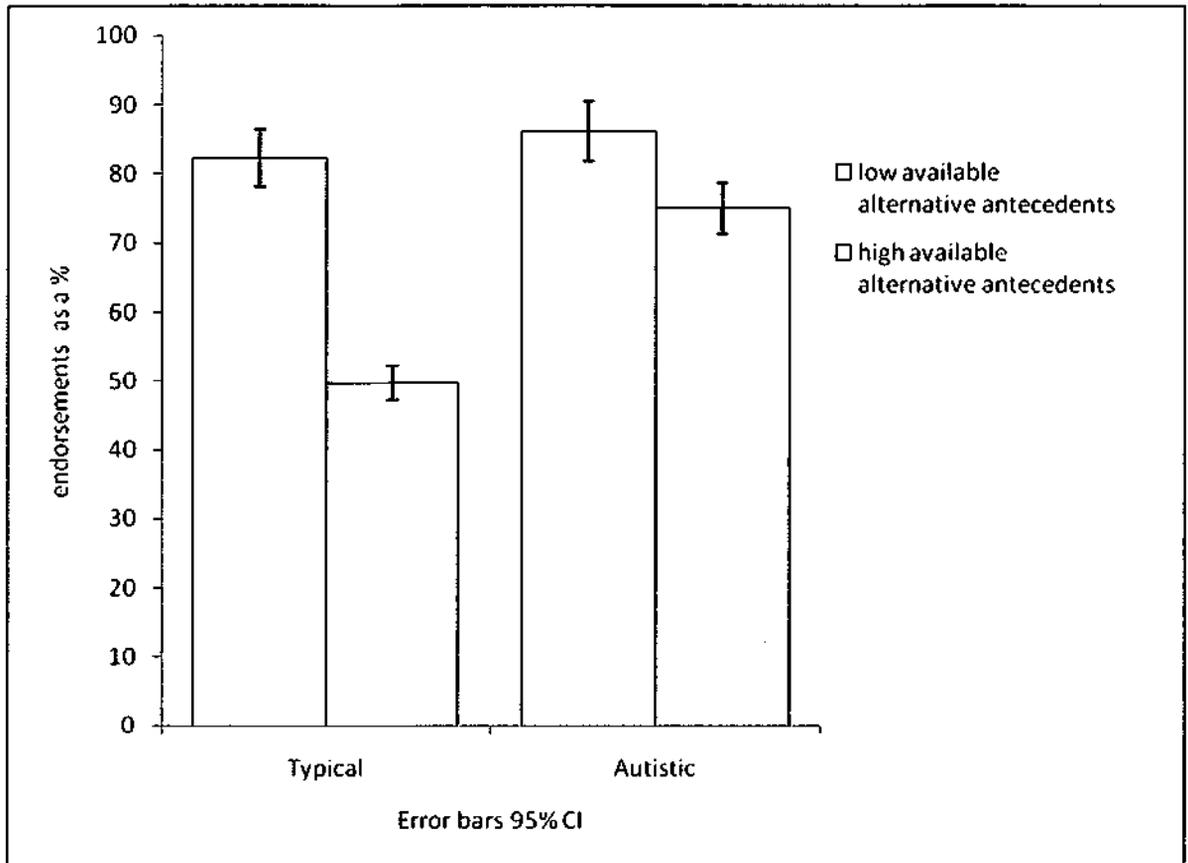


Figure 3.2. Mean number of endorsement responses as a percentage for AC questions with high and low available alternatives by autistic and typical groups.

Once again, follow-up t tests were performed to check for an effect of alternatives in the two groups separately. In this case, paired sample t tests showed a significant difference in endorsement rates on AC between high and low alternative questions for both groups. Consistent with the significant interaction, this trend was considerably more marked in the typical group ($t(37) = -6.48$ $p < .001$), than in the group with autism ($t(25) = 2.03$ $p = .04$).

Probability judgment task

The probability judgment task was included to measure the relevant associative beliefs concerning the relation expressed in each conditional statement. The purpose of the task was to ensure that any differential effects of counterexamples between the two groups could not be attributed to differences in underlying beliefs.

Responses for $P(q|p)$ and $P(p|q)$ statements, comparing autistic and typical groups are shown in Table 3.3.

Table 3.3. Mean likelihood ratings given by both groups to statements with high or low available counterexamples in Experiment 1.

	Autistic		Typical	
	Mean	SD	Mean	SD
High available alternatives ($p(p q)$)	3.69	0.87	3.54	0.62
Low available alternatives ($p(p q)$)	4.32	0.78	4.41	0.48
High available disablers ($p(q p)$)	4.23	0.68	4.17	0.47
Low available disablers ($p(q p)$)	4.22	0.62	4.35	0.53

A 2 (group) by 2 (low vs high disablers) repeated measures Anova was performed on the $P(q|p)$ data from the probability judgment task. The main effect of disablers was not found to be significant ($F(1,62) = 1.66$, $MSE = 0.49$, $p = .20$ $\eta^2_p = .03$). The two-way interaction between disablers and autism was also not found to be significant ($F(1,62) = 2.07$, $MSE =$

0.49 $p = .16 \eta^2_p = .03$), such that disablers did not affect likelihood judgments for either group (See Table 3.3).

Follow-up t tests revealed that there were no significant differences between autistic and typical groups on $P(q|p)$ questions with low available disablers ($t(62) = -0.89 p = .38$) or $P(q|p)$ questions with high available disablers ($t(62) = 0.36 p = .74$).

A 2 (group) by 2 (low vs high alternatives) repeated measures Anova was also performed on the $P(p|q)$ data from the probability judgment task. The main effect of alternatives was found to be significant ($F(1,62) = 81.79, MSE = 0.85, p < .001 \eta^2_p = .57$). The two-way interaction between alternatives and autism was, however, not found to be significant ($F(1,62) = 1.93, MSE = 0.85, p = .17 \eta^2_p = .03$), such that available alternatives affected likelihood judgments for both groups (See Table 3.3).

Follow-up t tests once again revealed that there were no significant differences between autistic and typical groups on $P(p|q)$ questions with low available alternatives ($t(62) = -0.54 p = .62$) or $P(p|q)$ questions with high available alternatives ($t(62) = 0.78 p = .44$).

Discussion

In line with previous research, typically developing adolescents showed a significant effect of available counterexamples on conditional reasoning. The typical group were more likely to withhold MP, where there were higher numbers of available disabling conditions, and similarly more likely to give uncertainty responses to AC, where there were high numbers of alternative antecedents. Our hypothesis that this pattern of responding would not be mirrored by the group with ASD was confirmed. For both inferences we observed significant interactions, indicating that background knowledge had less influence on the reasoning of the adolescents with ASD. The adolescents with ASD showed no significant effect of background knowledge, in the form of disabling conditions, on the valid MP inference. The same group showed a

small effect of background knowledge, in the form of alternatives, on AC but significantly less contextual influence than the typically developing group. Hence, the results strongly support our prior hypothesis that spontaneous contextualization of reasoning would be reduced in adolescents with ASD.

Our findings support Frith's (1989; see also Happé & Frith, 2006) claim that individuals with ASD have a tendency not to process information in context. Other information processing accounts of autism such as Underconnectivity Theory similarly predict that individuals with ASD will not integrate information in order to arrive at contextualized reasoning outcomes. The Complex Processing Deficit account (Minshew et al. 1997; Williams, Goldstein & Minshew, 2006) proposes that individuals with ASD have a general impairment in processing complex information. A difficulty in drawing information together, in order to create concepts and schemas, means that incoming information cannot be processed with the support of a contextual framework. This impairment is only apparent in tasks which draw on limited cognitive resources. Less complex tasks, or those which generally make fewer demands on cognitive resources, will be unimpaired. This account may explain why the conditional reasoning task, which has been shown to be related to cognitive ability (Verschueren et al. 2004), presents difficulties for the group with ASD, whilst the likelihood task does not. The groups did not significantly differ on measures of working memory, however, and Minshew is not claiming that individuals with ASD have a problem with cognitive capacity as such, just that their more piecemeal processing approach without top down supportive mechanisms makes overwhelming cognitive demands when engaged in effortful, complex tasks.

An important feature of the research design is that the results cannot be interpreted in terms of good and bad reasoning, from a normative viewpoint, as is known to relate generally to cognitive ability (Stanovich, 1999). MP is a valid inference, which logically should be drawn. The fact that the typically developing adolescents were strongly influenced by prior beliefs in their tendency to endorse MP is, therefore, technically evidence of a cognitive bias - a bias

which was wholly absent in the group with ASD. However, since AC is an invalid inference, it is a logical error to endorse it. Any suppression of AC inferences due to availability of counterexamples is hence a *debiasing* effect. Examination of Figure 3.2 shows that for low counterexample cases endorsement rates of AC were similarly high in both groups. However, the availability of counterexamples debiased reasoning in the typical group much more strongly than in the group with ASD. So the effect of context is to decrease logical accuracy for MP but to increase logical accuracy for AC. The fact that the reasoning of the typical group was more belief-based in both cases hence shows that the difference between groups has nothing to do with logical reasoning ability as such.

If we take a broader view of rationality in reasoning than that provided by logic, however, it becomes apparent that the lack of spontaneous contextualization of reasoning will be a major handicap for adolescents with ASD in everyday thinking and reasoning. As Evans and Over (1996) have pointed out, in real life (as opposed to the psychological laboratory) it is adaptive to reason from *all relevant belief*. In this sense, it is perfectly rational for us to question arguments whose conclusions we disbelieve, or to fail to draw inferences from premises that seem to us to be untrue.

Contextualised thinking allows us to deal flexibly with a myriad of complex novel situations, seemingly without effort, and is known to be a powerful and primary effect which is difficult to override (e.g. see Evans & Over, 2004 for a review). The belief bias literature shows, even when instructed to do so, most people find it very hard to reason deductively based only on the material presented (e.g. Evans, Handley & Neilens, in press). In general, under such instructions, only those individuals with high cognitive capacity are able to reason logically where logic and belief are in conflict (e.g. Capon, Handley & Dennis, 2003; De Neys, 2006; Klaczynski, 2000). In normal adults this requires a strong effort to inhibit prior belief, as indicated by the fact that executive control areas of the pre-frontal cortex are activated when belief-logic conflict is successfully resolved in favour of logic (Goel & Dolan, 2003). It was not

the case that the group with ASD showed better developed inhibitory abilities, the Stop-Signal Task revealed no significant differences in inhibition performance between the two groups. In the case of the participants with ASD, therefore, it seems that no such effort at decontextualisation was involved to explain the lesser influence of belief on their reasoning. Rather, it appears that the usual contextualisation which normal reasoners struggle to suppress, does not occur with the adolescents with ASD to start with.

The possibility that the difference in performance between the two groups was driven by group differences in the believability of the conditional statements was also eliminated. The group with ASD did not significantly differ in the responses they gave in the likelihood judgment task compared to the typical group. Automatic associative belief based processes appear to be intact. As a consequence the group with ASD was able to arrive at a degree of belief in the conditional. This suggests that individuals with ASD may be able to contextualise inputs when contextualisation relies on implicit associative processes. Such processes have been shown to have a distinct influence on reasoning apart from the explicit influence of specific counterexamples (Verschuere, et al. 2005; Weidenfeld, et al. 2005).

The adolescents with ASD did not show the kind of contextualised reasoning typically found in an adolescent population. In some ways the reasoning performance of the group with ASD had more in common with reasoning patterns found amongst younger children. Young children show less influence of background knowledge compared to adolescents (Markovits & Janveau-Brennan, 1999). The explicit consideration of counterexamples is subject to development. Background knowledge takes time to accrue in long term memory, and retrieval processes also develop over time. Not only must children be able to retrieve such knowledge, however, they also need to understand conditional relationships. This involves the formation of complex schemas representing the relations between presented material and counterexamples (Markovits & Barrouillet, 2002). Very young children are limited in their ability to create such schemas. Information processing accounts of autism also predict that

reasoners on the autistic spectrum will tend not to form complex representational models, where it is necessary to integrate presented material with other relevant knowledge.

Implicit probabilistic influences on reasoning are less cognitively demanding and are not subject to development to the same extent. Children as young as 6 years of age, for example, are able to make probabilistic judgments about conditional statements (Markovits & Thompson, 2008). This was also found to be the case with the adolescents with ASD. They showed no impairment in their ability to arrive at probabilistic judgments of presented material.

There are a number of possible reasons why the adolescents with ASD are less influenced by background knowledge in conditional reasoning. Firstly, it may be that, as for much younger children, they simply do not have the same kind of available knowledge in long term memory compared to typical adolescents. It may also be the case that, regardless of availability, they fail to generate counterexamples during the reasoning process. There is prior evidence, for example, that individuals with ASD show impairment in the generation of novel thoughts and ideas (e.g. Bishop & Norbury, 2005; Turner, 1999). Additional explanations stem from information processing accounts of autism which suggest that a tendency not to integrate information results in a failure to contextualize stimuli. Finally, our findings may reflect evidence that children with ASD show a positive response bias when engaged in reasoning (Leevers & Harris, 2000). The experiments presented in Chapter 4 seek to distinguish between these possibilities.

Chapter 4

Introduction

Experiment 1 found that adolescents with ASD were less influenced by background knowledge compared to typically developing adolescents, when engaged in conditional reasoning. This finding was not related to differences in working memory, inhibition or expressive vocabulary. In addition, it was found that the group with ASD and the typical control group did not differ in judgments concerning the believability of the relations described in the premises. Patterns of performance in the conditional reasoning task, therefore, did not reflect differences in participant's underlying beliefs in the conditional statements. These findings reflect research in other domains showing that individuals with ASD do not process stimuli in context, due to a tendency not to integrate information for higher meaning (See Happé & Frith, 2006 for a review). In addition to the hypothesis that individuals with autism tend not to integrate background knowledge during reasoning, there are a number of alternative explanations which will be explored in this chapter. Such explanations include the possibility that the adolescents with autism exhibited an affirmative response bias, that they had different amounts or kinds of information available in long term memory compared to controls, or that they did not generate counterexample cases.

One possible explanation for the results of the conditional reasoning task relates to the pattern of responses given by the adolescents with ASD. Although the correct logical response for the invalid inference AC is one of uncertainty, there is a tendency for people to endorse invalid inferences where little background knowledge is available. This is reflected in the high numbers of endorsements by both groups in response to AC questions with few alternative antecedents. Since the correct logical response for MP is also to endorse the inference, there is a tendency among typical populations for affirmative responses to be given to both MP and AC, when reasoning outside of empirical knowledge. This pattern of

responding is also shown by the participants with ASD, where available counterexamples are low. Where background knowledge is available, typical groups are less likely to endorse MP and AC, and give less affirmative responses for both inferences. Hence, it is possible that the adolescents with ASD do not show this drop in affirmative responding because they simply have a stronger tendency to respond by saying yes. There is some previous evidence that younger children with autism may exhibit a yes bias when engaged in contrary-to fact reasoning tasks which require the participant to reason on the basis of material that is empirically false. Leavers and Harris (2000) found that children with autism showed a positive response bias when answering contrary-to-fact questions such as:

All swans are red.

Slinky is a swan.

Is Slinky white?

Contrary-to-fact reasoning is very different from the kind of everyday conditional reasoning presented here. It is possible, nevertheless, that a yes response bias could explain the findings of Experiment 1. Experiment 2 examines this possibility.

A further possible explanation for the results of Experiment 1 derives from the availability of knowledge in long term memory and the generation of that knowledge. Individuals with ASD have been shown to have restricted and obsessive areas of interests (Murray, Lesser & Lawson, 2005) and to show impairment in the generation of novel thoughts and ideas (e.g. Bishop & Norbury, 2005; Turner, 1999). For the group with ASD, relevant background information may not be available, either because they did not generate available counterexamples or because they did not have the relevant information in long term memory. The pretest in Experiment 1 that allowed the classification of materials into low vs high disablers and alternatives was carried out on a group of typically developing children. It is possible that the adolescents with ASD did not have access to the same number or type of counterexamples for these materials. Experiment 3 explores, therefore, whether the pattern of

reasoning performance found among the adolescents with ASD was related to the availability of knowledge in memory. Adolescents with ASD and typical controls were compared on their ability to generate the counterexample cases involved in the reasoning problems of Experiment 1.

In considering the ability of individuals with ASD to generate counterexamples it is important to distinguish between the ability to generate cases when prompted to do so, and the ability to generate counterexamples when engaged in online reasoning. Experiment 1 explored the spontaneous activation and integration of contextual information during reasoning, amongst individuals with ASD. In seeking to explain the lack of contextual influence found in the group with ASD, one possibility is that counterexamples do not spontaneously come to mind for these participants during reasoning. Another is that, while available, counterexample cases are not integrated with the reasoning process, hence failing to affect it. In Experiment 4 the conditional suppression paradigm (Byrne, 1989) is adopted, a method which actively prompts counterexample cases within the reasoning task itself. With this method, some participants are presented with an extra premise: a second conditional statement which directly prompts consideration of a counterexample. Counterexamples are actively prompted by the suppression task, so participants do not need to spontaneously generate them. A lack of contextualized reasoning, in this case, would strongly suggest that counterexample information is not being integrated with the premises. This in turn might indicate that it is not the spontaneous activation of counterexamples that presents a problem, but the integration of those counterexamples into the reasoning process.

Experiment 2

The purpose of Experiment 2 was to explore the possibility that the pattern of responding shown by the adolescents with ASD, in Experiment 1, was related to a generalised yes

response bias. Adolescents with ASD and typically developing adolescents were given a reasoning task with equal numbers of affirmative and negative correct responses.

Method

Participants

As far as possible the participants reflected the same populations as in Experiment 1. The adolescents were recruited from the same schools and within the same age range. 20 adolescents with ASD, 14 of which had taken part in Experiment 1 and 38 typically developing adolescents were included in the study. The adolescents in both groups were between the ages of 11 and 16. There were 16 boys and 4 girls in the group with ASD and 21 boys and 17 girls in the typical group. All of the adolescents with ASD had a clinical diagnosis of autism spectrum disorder meeting either DSM-IV (APA, 1994) or ICD-10 (WHO, 1993) criteria. Diagnoses were performed by either a paediatrician or child and adolescent psychiatrist following multidisciplinary assessment. Adolescents with ASD with an additional medical diagnosis, such as attention deficit hyperactivity disorder, or who were taking medication, were excluded. There were 17 high functioning adolescents diagnosed as having ASD or autism and 3 adolescents diagnosed with asperger syndrome. Within the typically developing group, children were excluded if they had a diagnosis of autism spectrum disorder, asperger syndrome or were documented as having autistic traits. Children who had a statement of special educational needs were also excluded. Recruitment was from mainstream schools in lower middle class urban areas within Plymouth and West Devon. English was the first language for all of the participants.

All participants were given a working memory measure based on that developed by Case, Kurland and Goldberg (1982) including both a processing and storage component. Working memory was measured as it has been shown to be highly correlated with general intelligence (Colom, Rebollo, Palacios, Juan-Espinosa & Kyllonen, 2004) and reasoning ability (Kyllonen

& Christal, 1990). All participants were also given a subtest of The Wechsler Intelligence Test for Children (WISC–III, Wechsler, 1991) measuring expressive vocabulary. No significant differences between groups were found (See Table 4.1) for chronological age ($t(56) = 0.69$ $p = .49$), age corrected standard vocabulary scores ($t(56) = -1.55$ $p = .13$) or working memory span ($t(56) = -1.75$ $p = .09$).

Table 4.1. Measures of participant characteristics for the typical group and the group with ASD in Experiment 2.

	Autistic		Typical			Differences between groups	
	Range	Mean	SD	Range	Mean	SD	<i>P</i>
Chronological Age (Months)	141-195	166.45	15.79	137-194	163.29	16.90	.49
Standardised Vocabulary scores	4-11	6.50	2.14	4-13	7.37	1.96	.13
Working Memory Span	1.0-5.0	3.15	1.03	1.0-5.0	3.66	1.06	.09

Materials and procedure

The participants were presented with simple arguments based on a universally quantified major premise (shown in Appendix A2). The structure of the questions was taken from the Leavers and Harris (2000) study which found evidence for a yes response bias in children with ASD. The children in this study were younger than the participants in the current study and Experiment 1, ranging between 7 and 15 years. The materials used also differed from those in the Leavers and Harris study, in that the questions were not contrary-to-fact. The questions used here were similar in content to the problems in Experiment 1, in so far as they referred to familiar everyday information which did not conflict with empirical knowledge.

Sixteen questions were presented, four of each type of inference (MP, MT, AC and DA).

All participants were presented with the following instructions:

I am going to read some statements and some questions out to you. You need to listen carefully and think about what follows based on the statements. You need to answer the questions by circling either YES or NO.

For each inference there were two questions with standard affirmative conclusions, where drawing the inference involves responding 'yes', as in the following example:

All birds have feathers.

Robins are birds.

Does it follow that robins have feathers?

There were also two questions with opposite conclusions, where drawing the inference involves responding 'no', for example:

All fires are hot.

A bonfire is a fire.

Does it follow that a bonfire is cold?

If the participants with ASD show a bias to say 'yes' then this will be manifested in reduced rate of drawing the inference on problems with opposite conclusions. The questions were presented in a booklet. All materials were read out loud by the experimenter and participants were required to circle either a 'yes' or 'no' response. Participants were tested in small groups of up to 5 individuals.

Results

Table 4.2 shows rates of inference for the four argument forms under standard and opposite conclusions for the two groups. The presence of a bias to respond 'yes' would be indicated by lower inference rates amongst the ASD participants on problems with opposite conclusions.

A 4 x question type (MP, MT, AC and DA) by 2 x conclusion type (standard or opposite)

repeated measures Anova on inference rates, with autism as a between subjects factor, revealed a significant main effect of question type ($F(3,168) = 3.30, MSE = 0.13, p = .02, \eta^2_p = .06$) and a significant two way interaction between question type and conclusion type ($F(3,168) = 3.47, MSE = 0.14, p = .02, \eta^2_p = .06$), showing higher rates of inference for standard than opposite conclusions on the denial inferences, MT and DA. Crucially, however, the two way interaction between conclusion type and group was not significant ($F(1,56) = 1.04, MSE = 0.11, p = .31, \eta^2_p = .02$). This shows that there was no significant tendency amongst the participants with ASD to generate 'yes' responses more often than the typical participants. The three-way interaction between question type, expected response and group was also non-significant ($F(3,168) = 0.34, MSE = 0.05, p = .80, \eta^2_p = .01$).

Table 4.2 Mean number of inferences drawn for standard and opposite conclusions for each argument form comparing groups in Experiment 2.

Inference	Response type	ASD	Typical
MP	Standard	1.85	1.89
	Opposite	2.00	1.97
MT	Standard	1.85	1.89
	Opposite	1.75	1.79
AC	Standard	1.90	1.97
	Opposite	1.90	2.00
DA	Standard	1.90	1.92
	Opposite	1.75	1.71

Follow up t tests revealed no significant differences between groups in inference rates for standard or opposite conclusions on any of the argument forms. For MP questions with standard conclusions ($t(56) = 0.49, p = .63$), MP questions with opposite conclusions ($t(56) = -0.72, p = .47$), MT opposite questions ($t(56) = 0.34, p = .74$), MT standard questions ($t(56) =$

0.43 $p = .67$), AC standard questions ($t(56) = 1.20$ $p = .33$), AC opposite questions ($t(56) = 1.39$ $p = .33$), DA opposite questions ($t(56) = -0.29$ $p = .77$), DA standard questions ($t(56) = 0.22$ $p = .83$).

Discussion

Experiment 2 shows that the adolescents with ASD do not differ significantly from typically developing adolescents in the number of yes responses given to the reasoning problems. The pattern of findings shown in Table 4.2 also demonstrates that the adolescents with ASD are engaged in reasoning, and do not significantly differ from the typical group in the responses given, regardless of whether the standard response is affirmative or not. The adolescents with ASD, do not, therefore, show a yes-saying response bias, compared with typical controls.

Previous studies of contrary-to-fact reasoning among children with autism present conflicting findings (Leevers & Harris, 2000; Scott, Baron-Cohen & Leslie, 1999). These differences have been explained by reference to a yes response bias (Leevers & Harris, 2000). One important difference between the Leevers and Harris study and work reported here is that the current study used questions with familiar information, which was in line with empirical knowledge about the world.

It is also the case that no significant differences were found between the two groups in their ability to reason logically. This was not so in the Leevers and Harris study where responses for the group with autism were not found to be characterised by an empirical or logical approach, but rather reflected random responses, or a strong bias to answer all questions by saying 'yes'. The fact that participants with ASD were able to engage in logical reasoning in the current task, and did not show a yes response bias, suggests that the pattern of responding among children with ASD seen in previous studies may be particular to reasoning with content that is not empirically true. The tendency for children with ASD not to engage in imaginary play (see Jarrold, 2003 for a review), and to have difficulties understanding

pretence (Nielsen & Dissanayake, 2001), and non-literal aspects of language (Tager-Flusberg, 2000) would also suggest that this might be the case.

Experiment 3

The purpose of Experiment 3 was to explore the possibility that a lack of contextualized reasoning among adolescents with ASD was related to the availability of counterexamples in long term memory, and the ability to generate such counterexamples. The ability of typically developing adolescents and adolescents with ASD to generate disabling conditions and alternative antecedents was measured by performance on a generation task, based on that of Cummins et al. (1991).

Method

Participants

Participants for the generation task included 32 typically developing adolescents and 20 adolescents with ASD. All of the participants had previously taken part in Experiment 1. Once again no significant differences were found on measures of chronological age ($t(50) = 0.46$ $p = .65$), age corrected standard vocabulary scores ($t(50) = -1.22$ $p = .23$), inhibition ($t(50) = 2.04$ $p = .08$) or working memory ($t(50) = 0.95$ $p = .35$).

Materials and procedure

The participants were presented with a booklet containing eight conditionals, four AC and four MP statements, taken from each of the four high-low categories identified by the pretest in Experiment 1 (See Appendix A3). Participants were given the following instructions:

In this task you will be given some riddles. You will be told a rule. You will then be told a fact about an event. You have one and a half minutes to think of as many reasons as you can that make the event possible.

All materials were read aloud by the experimenter. Participants were presented with a practice example, then 8 statements in the form of rules and facts. The questions referred to either AC as in the following practice example:

Rule: If Marvin wears wellies, then his feet will stay dry.

Fact: Marvin's feet stay dry, but he is not wearing wellies.

Give as many reasons as you can that could make this possible.

Or MP:

Rule: If butter is heated, then it will melt.

Fact: Butter is heated, but it does not melt.

Give as many reasons as you can that could make this possible.

Results

The responses given were categorized into four types based on Verschueren et al. (2002). Types ranged from those which are strongly related to the content of the premises to those which represent more remote situations. The examples given here refer to the following rule and fact:

Rule: If the ignition key is turned, then the car will start.

Fact: The car started, but the ignition key was not turned

Type 1 constituted 'real' counterexamples where either an alternative cause which would lead to the same effect is generated, or an event which would stop the effect from occurring as in the following example:

'The car was hotwired'

Type 2 referred to answers which state that there are possible exceptions, although they are not explicitly stated:

'He was a mechanic and knew something else to make the car start'

Type 3 referred to answers which state that an enabler is not necessary, for example, the given cause is not necessary for the effect to occur:

'You don't need a key to start some cars'

Type 4 included more remote answers referring to generalizations, invalid rules and fantastical intervening instances, for example:

'The car started by magic spell'

Responses which fell outside these four types were not included in analysis. Excluded responses included reasons which bore no relation to the question, incomplete responses or those which simply repeated the statement. A total of all acceptable responses were calculated for each participant, for each question. Means for each type of counterexample generated and total counterexamples generated are shown in Table 4.3.

Table 4.3 Mean number of counterexamples generated for each type by the typical group and the group with ASD in Experiment 3.

Type generated	Autistic		Typical	
	Mean	SD	Mean	SD
Real counterexamples	12.10	4.89	11.75	3.16
Possible exceptions	0.15	0.67	0.13	0.34
Missing enablers	2.15	1.81	2.34	1.29
Remote counterexamples	0.40	0.68	0.72	0.99
Total counterexamples	14.80	5.79	14.94	3.67

Multivariate analysis revealed no significant difference between autistic and typical groups in terms of overall numbers of counterexamples generated, $F(2,49) = 0.32$ $p = .73$ $\eta^2_p = .01$. Follow up Univariate Anovas also revealed no significant differences between groups in terms of types of counterexamples generated (See Table 4.3).

Further analysis was performed on numbers of counterexamples generated for MP and AC questions with low/high available counterexamples, as identified in Experiment 1. Means and standard deviations are shown in Table 4.4.

Table 4.4 Mean number of counterexamples generated by the typical group and the group with ASD, for questions with low/high available disablers and alternatives in Experiment 3.

Availability of counterexamples	Autistic		Typical	
	Mean	SD	Mean	SD
Low available disablers	2.55	1.39	2.71	1.20
High available disablers	4.95	2.44	5.41	1.88
Low available alternatives	1.60	1.04	1.75	0.92
High available alternatives	5.75	2.47	5.94	1.68

A 2 (group) by 2 (high vs low disablers) Anova was performed on the numbers of acceptable counterexamples generated for MP questions, with autism as a between subjects factor. The analysis revealed a main effect of disablers ($F(1,50) = 68.16, MSE = 2.34, p < .001 \eta^2_p = .58$) showing that participants generated more counterexamples on those problems found to have higher numbers of available disablers in Experiment 1. The two-way interaction between disablers and autism was not found to be significant ($F(1,50) = 0.22, MSE = 2.34, p = .64 \eta^2_p = .004$), such that there was no significant difference in generation performance between the two groups.

An equivalent Anova was performed on the data for AC questions. The analysis revealed a main effect of alternatives ($F(1,50) = 278.82, MSE = 1.53, p < .001 \eta^2_p = .85$) In line with the previous analysis of disabling conditions the two-way interaction between alternatives and autism was not found to be significant ($F(1,50) = 0.01, MSE = 1.53, p = .94 \eta^2_p = .00$) showing, once again, that there was no significant difference in generation performance between the two groups.

A measure of the influence of counterexamples in the reasoning task from Experiment 1 across all inferences was also derived by calculating the difference between levels of endorsement where many counterexamples were available compared to cases where few counterexamples were available. As expected, the means for the group with ASD ($M=0.85, SD=2.60$) and the control group ($M=3.58, SD=3.52$) were found to significantly differ ($t(62) = 3.37 p = .001$). Since all the participants in Experiment 1 also took part in this experiment it was possible to correlate this measure with total numbers of counterexamples generated. Remote or invalid type 4 examples were excluded. Among typical participants we would expect that higher influence of counterexamples during reasoning would be associated with higher numbers of counterexamples generated. Analysis revealed significant correlations between the influence of counterexamples during reasoning and numbers of counterexamples

generated for the typical group $r(32) = 0.39, p = .03$, but not for the group with ASD $r(20) = 0.16, p = .49$. The significance of the difference between the two correlations was, however, not found to be significant using Fisher r-to-z transformation ($z = 0.82, p = 0.21$).

Discussion

Experiment 3 shows that the typical group and the group with ASD did not differ in the numbers or type of counterexamples generated. Both groups, therefore, appear to have similar background information available for activation. These findings also show that the adolescents with ASD are able to retrieve background knowledge when instructed to do so. There is still a possibility, however, that they do not spontaneously activate such background knowledge during reasoning. These results appear to conflict with previous studies showing an impairment in the generation of novel ideas. The fact that the participants with ASD were able to generate counterexamples may be related to the fact that they were explicitly cued to do so.

Analysis revealed significant correlations, for the typical group, between the influence of counterexamples during reasoning and the generation of counterexamples. For the group with ASD the ability to generate counterexamples when instructed to do so was not related to reasoning performance. The difference between the two correlations was not, however, found to be significant. Conclusions about differences between the groups in terms of the relationship of the generation of counterexamples to reasoning performance, therefore, remain tentative.

Experiment 4

The purpose of Experiment 4 was to explore two plausible explanations for a lack of contextualized reasoning among the adolescents with ASD in Experiment 1. One possibility is that counterexamples do not spontaneously come to mind for the ASD participants during

reasoning, despite their ability to generate counterexamples when asked to do so, as demonstrated in Experiment 3. Another is that, while available, counterexample cases are not integrated during online reasoning consequently failing to influence reasoning outcomes. In this experiment we adopt the conditional suppression paradigm (Byrne, 1989), a method which actively prompts counterexamples within the given reasoning task. For example:

If Mary has an essay to write, then she will study late in the library.

(If the library stays open, then Mary will study late in the library.)

Mary has an essay to write

Does it follow that she will study late in the library?

With the standard presentation, which omits the conditional statement shown in parentheses, most participants draw the valid MP inference. When the second conditional is presented, however, then a disabling condition is prompted: Mary may not be able to stay late if the library closes. These cases are known as *additional arguments*, since the second conditional suggests an additional condition required to achieve the consequent. Participants in this group make the valid MP and MT inferences less often. In the same way, fallacies like AC and DA can be suppressed when a second conditional prompts consideration of an alternative antecedent, as in the following case:

If Mary has an essay to write, then she will study late in the library.

(If she has a textbook to read, then she will study late in the library.)

Mary studies late in the library

Does it follow that she has an essay to write?

These cases are known as *alternative arguments*, because they suggest an alternative means by which the consequent may be achieved. When told that Mary studies late in the library and asked if it follows that she has an essay to write, the tendency will be to infer that there may be other possible causes, and hence suppress the AC inference. Mary may have an essay to write or she may have a textbook to read. In this case the alternative argument lessens the tendency to endorse the inference and encourages a logical uncertainty response. Examples of both additional and alternative arguments used in Experiment 4 are shown in Appendix A4.

If the participants with ASD do not spontaneously generate counterexamples during reasoning, then this paradigm will alleviate the need for spontaneous generation by providing explicit prompts referring to counterexample cases. In this case more influence of background knowledge would be expected among participants with ASD on this reasoning task compared to that used in Experiment 1. If, on the other hand, the adolescents with ASD are able to generate counterexamples but do not integrate available information during reasoning, similar reasoning performance to that found in the first experiment would be expected.

Method

Participants

High functioning participants with ASD were recruited from mainstream schools known to have special units and one special school supporting pupils on the autistic spectrum. Four of the participants had also taken part in previous experiments. Adolescents with ASD were included if they had a definitive clinical diagnosis of autism or asperger syndrome meeting either DSM-IV (APA, 1994) or ICD-10 (WHO, 1993) criteria. As in previous experiments diagnoses were carried out by a pediatrician or child and adolescent psychiatrist after multidisciplinary assessment. Adolescents with ASD who had a medical diagnosis such as

epilepsy or a neurodevelopmental diagnosis in addition to autism or who were taking medication, were excluded.

Typically developing participants were recruited from within the same mainstream schools and were excluded if they had a diagnosis of ASD or a statement of special educational needs. None of the typical group had taken part in previous experiments. Participants in both groups were between 11 and 16 years of age.

Participants were given individual difference measures including 'The Counting Span Task' (Case et al.,1982) used in Experiment 2. As in Experiment 2 the expressive vocabulary test of The Wechsler Intelligence Test for Children (WISC-III, Wechsler, 1991) was also given to all participants.

40 typically developing participants and 25 high functioning participants with ASD were included in the study. No significant differences between the groups were found (See Table 4.5) for chronological age ($t(63) = 1.78 p = .08$), scaled score equivalents for vocabulary ($t(63) = -1.98 p = .07$) or working memory span ($t(63) = -1.49 p = .14$).

Table 4.5. Individual difference measures for the typical group and the group with ASD in Experiment 4.

	ASD (N=25)			Typical (N=40)			Differences between groups
	Range	Mean	SD	Range	Mean	SD	P
Chronological Age (Months)	139-192	170.80	17.58	137-194	162.68	18.09	.08
Vocabulary (scaled score)	3.0-12.0	6.16	2.76	3.0-13.0	7.35	2.07	.07
Working Memory Span	1.5-5.0	3.42	0.98	0.5-5.0	3.79	0.96	.14

Materials and procedure

All materials were presented by a robot character on a computer who read all instructions and questions out loud. The materials consisted of two programs presenting alternative or additional arguments. In the first program, participants were given 16 statements with four questions of each inference type, The two valid inferences Modus Ponens (If p then q , p/q) and Modus Tollens (If p then q , not- q /not- p) and the two invalid inferences, Affirmation of the Consequent (If p then q , q/p) and Denial of the Antecedent (if p then q , not- p /not- q). Half of the questions for each inference type were presented as simple statements without extra information, which acted as control questions. The other half were presented with extra information in the form of alternative arguments. The program presenting additional arguments followed the same pattern (All the questions used are shown in Appendix A4). All participants completed both programs. Half of the participants received the alternative arguments program first, and half received the additional arguments program first.

All participants were given with the following instructions and simple example:

I am going to give you some problems to work out. I will read some sentences out to you. I want you to assume that what you hear is true. Then I will ask you to think about what follows from the sentences. There will be three answers to choose from and I want you to decide which one of the answers is correct based on the sentence. It is important that you listen and answer each question carefully.

Let's look at an example together.

Listen to these sentences and suppose they are true.

If Joan is lucky, then she wins a prize.

Joan is lucky.

Does it follow that?

1. *Joan wins a prize*
2. *Joan does not win a prize*
3. *Joan may or may not win a prize*

Results

Mean rates of endorsement for simple, additional and alternative arguments are presented in Table 4.6. Endorsements in the simple control condition are comparable for both valid and invalid inferences.

Table 4.6 Mean rates of endorsements for the typical group and the group with ASD comparing simple with alternative and additional arguments in Experiment 4.

Additional	MP		MT		AC		DA	
	Simple	Additional	Simple	Additional	Simple	Additional	Simple	Additional
Autistic	3.12	3.00	2.56	2.24	3.08	2.88	2.72	2.12
Typical	3.60	2.73	3.33	2.40	3.60	3.23	3.28	2.85

Alternative	MP		MT		AC		DA	
	Simple	Alternative	Simple	Alternative	Simple	Alternative	Simple	Alternative
Autistic	3.04	3.36	2.84	2.92	3.00	2.04	3.00	1.80
Typical	3.63	3.33	3.33	2.90	3.58	1.53	3.50	1.50

This pattern of responding is customary for children and younger adolescents. Children tend to interpret inferences biconditionally (if and only if p then q) and consequently tend to respond with certainty to AC and DA (Markovits, 2000; Markovits, Venet, Janveau-Brennan, Malfait, Pion, & Vadeboncoeur, 1996). The ability to respond consistently with uncertainty to

invalid inferences develops across adolescence (Muller et al., 2001) and would not be expected, particularly among our younger participants (Janveau- Brennan & Markovits, 1999).

The data for the additional and alternative arguments blocks were analysed separately. For the additional arguments block, a 2x argument (additional and simple) 2x validity (valid and invalid) and 2x endorsement (affirmative endorsements for MP and AC or negative endorsements for MT and DA) analysis of variance was performed, with autism as a between participants factor. This revealed a main effect of argument ($F(1,63) = 16.24, MSE = 1.75, p = <.001 \eta^2_p = .21$) and a significant three-way interaction between argument, validity and group. ($F(1,63) = 5.64, MSE = 0.63, p = .02 \eta^2_p = .08$) of the type predicted. That is the tendency to withhold valid inferences when an additional argument was present was more strongly marked in the typically developing than the ASD group, as illustrated in Figure 4.1.

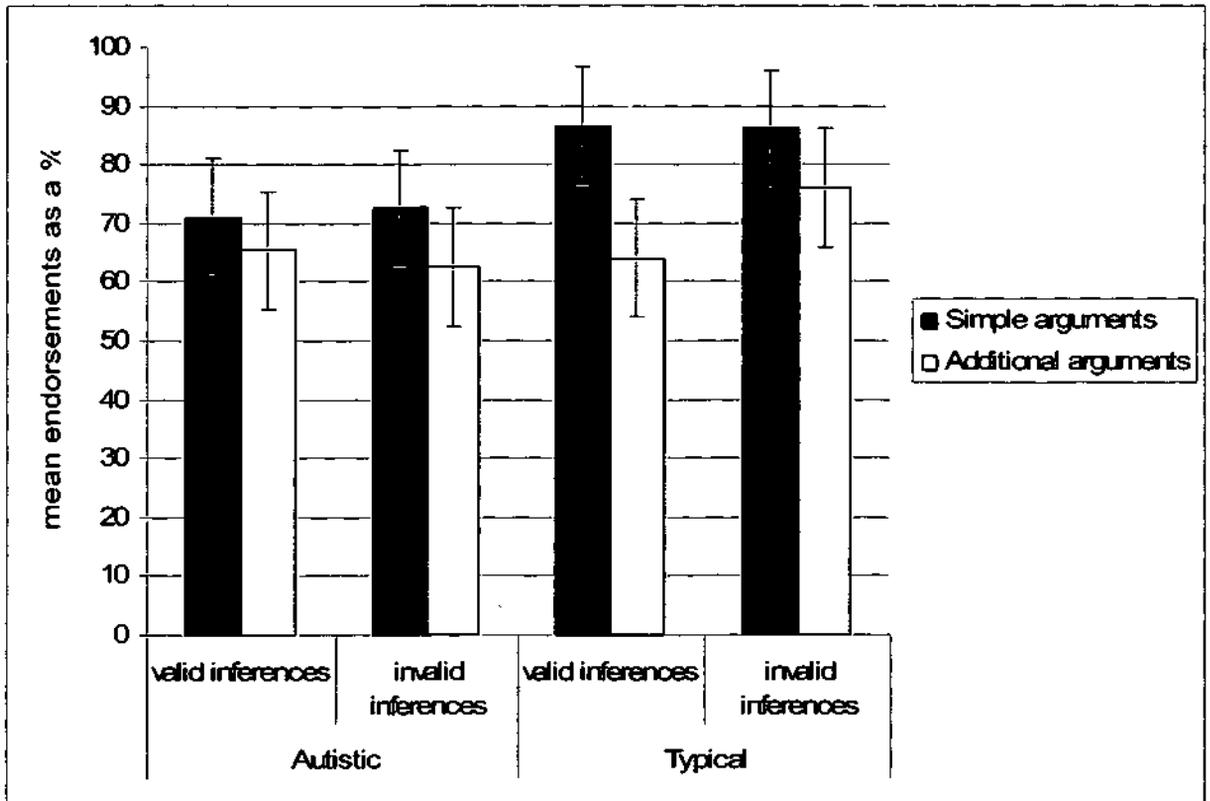


Figure 4.1 suppression effect with additional arguments comparing autistic and typical groups in Experiment 4.

Follow-up *t* tests were performed to check for an effect of additional arguments in the two groups separately. There was found to be a significant difference in levels of responding to additional and simple arguments for typical adolescents for valid inferences ($t(39) = -4.44$ $p = <.001$) and for invalid inferences ($t(39) = -3.09$ $p = .004$). For the group with ASD there was no significant difference in levels of responding to additional and simple arguments for valid inferences ($t(24) = -0.99$ $p = .33$), or for invalid inferences ($t(24) = -1.79$ $p = .09$).

An equivalent analysis was performed on the data where alternative arguments were presented. A 2x argument (alternative and simple) 2x validity (valid and invalid) and 2x endorsement (affirmative or negative endorsement) analysis of variance revealed a significant main effect of argument ($F(1,63) = 56.58$, $MSE = 1.45$, $p = <.001$ $\eta^2_p = .47$) and validity ($F(1,63) = 39.83$, $MSE = 1.41$, $p <.001$ $\eta^2_p = .39$), and a two-way interaction between validity and argument ($F(1,63) = 67.28$, $MSE = 0.99$, $p <.001$ $\eta^2_p = .52$), indicating a greater effect of alternative premises on invalid compared to valid arguments. There was also a two-way interaction between argument and group ($F(1,63) = 12.04$, $MSE = 1.45$, $p = .001$ $\eta^2_p = .16$) such that the effect of alternative arguments on all inferences was greater for the typical group than for the group with ASD. Mean endorsement rates for all inferences for both simple and alternative arguments are shown in Figure 4.2.

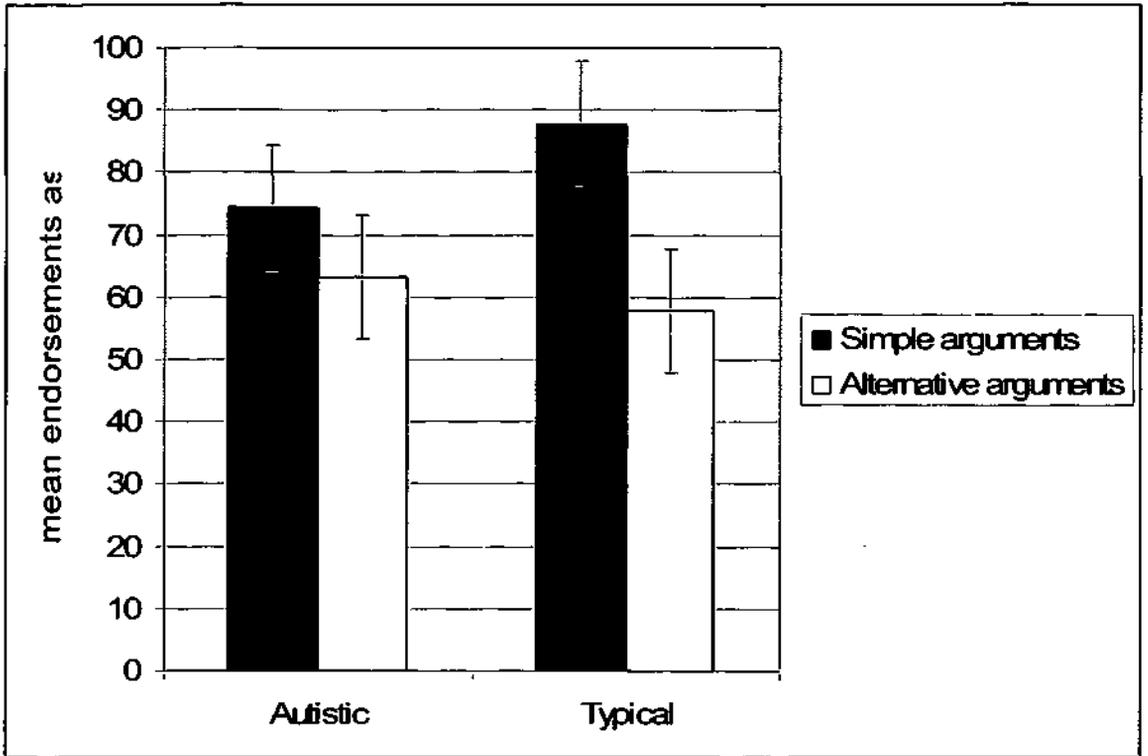


Figure 4.2 suppression effect with alternative arguments comparing autistic and typical groups in Experiment 4.

Discussion

The results of Experiment 4 demonstrate that the adolescents with ASD are substantially less influenced than controls by the presentation of contextual cues in the form of alternative and additional arguments during reasoning. This is the case for both valid arguments with additional requirements and invalid arguments with alternative causes. These findings extend those of Experiment 1 in demonstrating that, despite the provision of explicit contextual prompts, the individuals with ASD did not integrate background knowledge with the premises to the same degree as typical adolescents. These findings strongly suggest, therefore, that the tendency not to take account of background knowledge among the group with ASD is related to a tendency not to draw all available information together, rather than a failure to spontaneously generate background material.

General Discussion

Experiment 2 explored the possibility that the results of Experiment 1 reflected a yes response bias among the group with ASD. The adolescents with ASD were not found to differ from typically developing adolescents in their willingness to give negative responses. The possibility that the reasoning performance of the group with ASD reflected differential availability of counterexamples in long term memory was ruled out by Experiment 3, which showed no differences between groups on a counterexample generation task. Experiment 4 found that the adolescents with ASD were substantially less influenced in their conditional reasoning by the presentation of contextual cues in the form of alternative and additional arguments. This was the case for both valid arguments with additional requirements and invalid arguments with alternative causes.

The fact that a yes response bias was not exhibited by the adolescents with ASD contradicts previous studies. Leavers and Harris (2000) found that children with autism displayed a pattern of yes responding in response to contrary-to-fact reasoning problems, they also claim that the results of a similar study (Scott, Baron-Cohen & Leslie, 1999) reflect a yes bias among children with ASD. Unlike the questions used in Experiment 2, which were empirically true, both of these studies used contrary-to-fact materials. As the questions we used were very similar to those used in the Leavers and Harris study, but differed in content, it maybe that children with ASD have specific difficulties reasoning with empirically false material. There is comparable evidence that individuals with ASD show poor performance on counterfactual reasoning tasks involving reasoning about alternative possibilities not reflected in reality (Grant, Riggs & Boucher, 2004; Peterson & Bowler, 2000).

The fact that the participants with ASD were able to generate counterexamples also fails to support previous studies which show impaired generation of novel ideas. Individuals with ASD have shown restricted performance relative to controls in response to tasks involving

word fluency (generation of as many words as possible in a given time span) (e.g. Minshew, Goldstein, Muenz & Payton, 1992), ideational fluency (generation of as many uses as possible for a given object in a set time span) (e.g. Turner, 1999) and impairment in the spontaneous use of pretence in play (Jarrold et al., 1996). There are, however, other studies which show that individuals with ASD show no impairment in similar tasks (e.g. Boucher, 1988; Minshew, Goldstein and Seigel, 1995). Boucher demonstrates that individuals with ASD have a specific problem with the spontaneous generation of novel ideas when no cues are provided. The generation task involved very specific prompts in the form of rules and facts. Participants did not have to devise a generation strategy, they simply had to report the resulting counterexamples activated on the basis of the cues given. What is perhaps surprising, nonetheless, is that the group with ASD did not differ in terms of the types of counterexamples generated. Turner, for example, found that individuals with autism were able to report the usual uses, cued by a given object, but were unable to derive more imaginative or out of the ordinary responses not normally associated with the use of the target. It seems likely, therefore, that the typical group and the group with ASD would differ in the generation of remote or exceptional instances of counterexamples. This was found not to be the case. The results do show, however, that both groups show a marked tendency to generate 'real counterexamples' as opposed to generalisations and more remote or exceptional examples, where numbers generated by both groups were very low.

The results of Experiment 4 extend the previous findings of Experiment 1, which found that adolescents with ASD did not spontaneously contextualise conditional reasoning problems. In Experiment 4 the methodology differs, as background knowledge was actively prompted. Despite the provision of explicit contextual prompts, the individuals with ASD did not integrate available background knowledge with the premises to the same degree as typical adolescents. The adolescents with ASD were substantially less influenced in their conditional reasoning by the presentation of alternative and additional arguments. This was the case for

both valid arguments with additional requirements, and invalid arguments with alternative causes.

Experiment 4 refines interpretation of the results reported in Experiment 1. In the previous study it is possible that the group with ASD failed spontaneously to generate counterexamples. In Experiment 4, however, information specifically relating to counterexample cases was provided. In this case, it seems that the propensity not to contextualize given problems is the result of a tendency among participants with ASD not to integrate relevant and available contextual knowledge into the reasoning process.

For the typical group, the presentation of alternative arguments was associated with significantly lower endorsement rates for both valid and invalid problems. There is prior evidence that prompting a search for alternatives can also activate disabling conditions (Markovits & Potvin 2001). Markovits and Potvin claim that withholding valid inferences, in such cases, results from a failure to inhibit irrelevant material. In considering this paradigm it is important to note that contextualized reasoning involves the activation of generally associated background knowledge which may or may not be relevant. Specific prompts to activate alternative antecedents, for example, may also lead to retrieval of disabling conditions. The influence of activated knowledge will depend upon its relevance to the inference presented. This account may be applicable here, as compared to adults, adolescents are less able to employ metacognitive and inhibitory skills to deal selectively with activated information (Markovits & Barrouillet, 2004; Muller, Overton & Reene, 2001).

As indicated at the outset, there has been some debate in the psychology of reasoning as to whether contextualisation in reasoning should be viewed primarily as a source of bias, or as a normally adaptive mechanism which creates problems in the artificial world of deductive reasoning experiments. However, it is clear that prior knowledge does substantially influence and interfere with the capacity of normal participants to reason logically in compliance with the instructions given. Furthermore, the ability to *decontextualise* such problems, and hence

reason more logically, is associated with those of higher general intelligence (for reviews, see Stanovich, 1999; 2004; Evans & Over, 2004; Evans, 2007). In the current study, intelligence levels and working memory capacity were well matched in the ASD and typical groups, so this should not be a factor. Furthermore, our methodology controls for any influence of logical reasoning ability *per se*. As we have seen the influence of background knowledge in conditional reasoning can be both to suppress valid and invalid inferences, making it both a biasing and a debiasing influence from the viewpoint of logic. The ASD group was less sensitive to the context manipulation both on additional arguments (biasing) and on alternative arguments (debiasing). Hence, principal findings have nothing to do with differences in logical reasoning ability as such.

Since completion of the experiments described here a new study has been published which reports similar findings with an adult population. Pijnacker et al. (2009) employed the Suppression Task to investigate defeasible reasoning among adults with autism. This study explored the ability of high functioning adults with autism to revise conditional reasoning conclusions, on the basis of new contextual information in the form of additional or alternative arguments. Participants with autism showed no significant differences in performance, compared to controls, on simple conditional reasoning tasks where no extra statements were given. This was the case for both valid and invalid inferences. Where additional and alternative arguments were presented all participants showed a suppression effect with significantly fewer endorsements for all inferences. In the case of valid inferences, however, this effect was significantly less marked for the group with autism compared to controls. Pijnacker et al. claim, therefore, that the participants with autism exhibit a specific difficulty with exception-handling resulting in a tendency not to revise conclusions on valid inferences.

The focus of this study was very different to ours. We were interested in the effect of background knowledge on everyday reasoning whereas Pijnacker et al. were interested in

logical reasoning performance. Analysis of reasoning outcomes focused, therefore, on logically correct rather than endorsement responses. In the case of valid inferences, where endorsement and logical responses coincide, the group with autism showed less suppression of MP and MT where additional arguments were presented. For MP this difference was significant ($p = 0.008$) and for MT it was marginally significant ($p = 0.058$). Re-examination of the available data on endorsements for MP and MT. is shown in Figure 4.3.

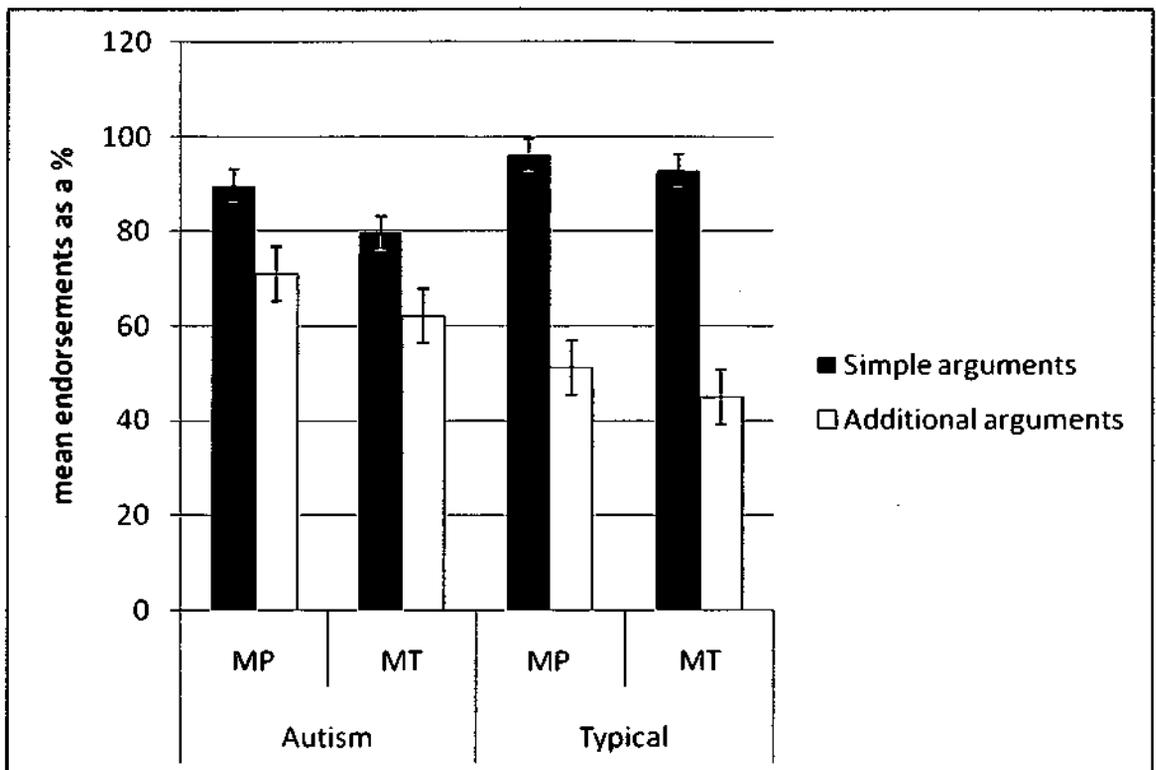


Figure 4.3 endorsement responses for valid inferences for the typical group and the group with autism. Graph derived from means taken from Pijnacker et al. 2009.

Where additional arguments were presented, the typical group show customary suppression of both MP and MT inferences. In other words, where explicit information refers to background knowledge the typical group are less likely to endorse the inferences. In the case of the adults with autism the effect of background knowledge is significantly less marked.

For the invalid inferences AC and DA the logically correct response is one of uncertainty, but there is a tendency for adults and particularly children to respond with certainty and endorse AC by responding 'yes' and DA by responding 'no'. The Pijnacker et al. study reports significant differences in endorsement responses for simple and alternative arguments on AC and DA for all participants. What is more difficult to ascertain, is whether this suppression effect is significantly less marked in the case of the participants with autism. A re-examination of available data for patterns of endorsement across all participants on AC and DA would suggest that this is the case (see Figure 4.4).

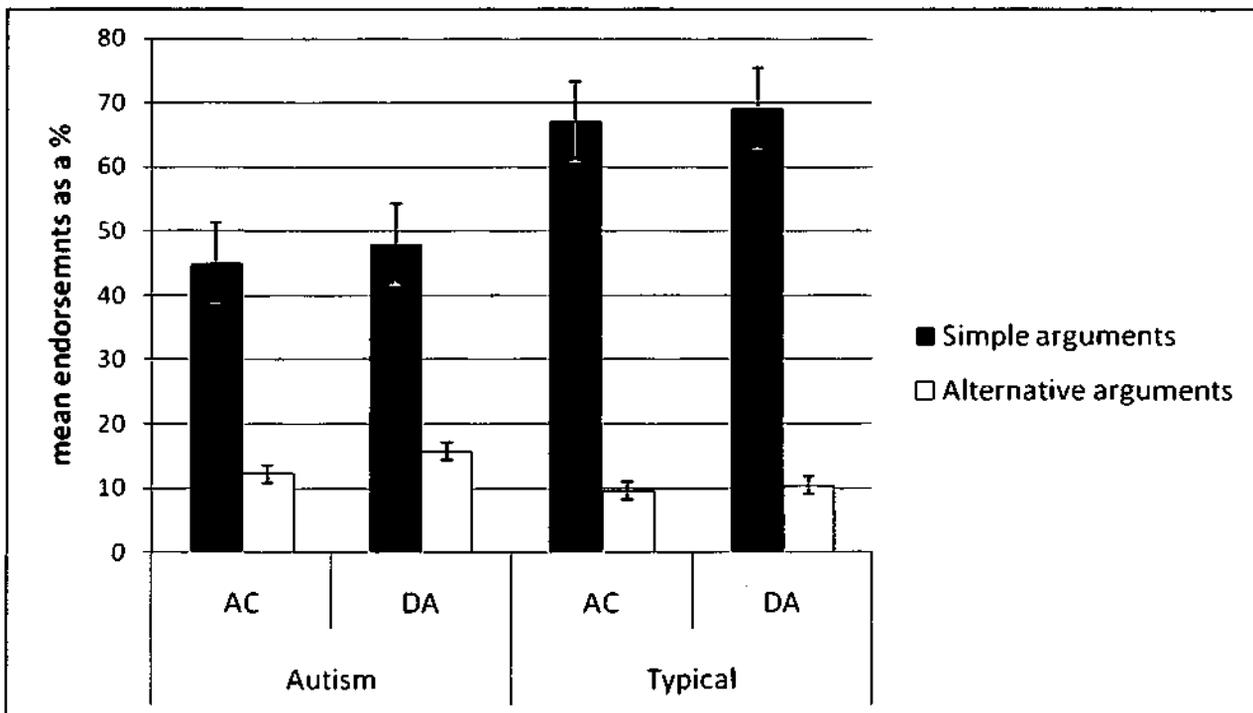


Figure 4.4

endorsement responses for invalid inferences for the typical group and the group with autism. Graph derived from means taken from Pijnacker et al. 2009.

Overall the data from the Pijnacker et al. (2009) study presents similar findings to those of Experiment 4. The current results and those of Pijnacker et al. show that the presentation of

extra contextual information influences the reasoning of individuals with ASD to a lesser extent than typical participants. The adults with ASD do appear, however, to show more influence of background knowledge on reasoning compared to adolescents with ASD. The findings of the two studies also differ, as Pijnacker et al. did not find an effect of alternative arguments on valid inferences. Given the age of the participants in the two studies, this finding would support the proposal that typical adolescents are less able to inhibit irrelevant material compared to an adult population.

Unlike high ability participants who can, with effort, decontextualise their reasoning, the present results suggest that the reasoning of the adolescents with ASD is not contextualized in the first place. In our daily lives, reasoning on the basis of all relevant knowledge allows us to pursue our goals and deal flexibly with a range of situations (Evans, 2007). This normally adaptive process of contextualizing reasoning appears absent (or weak) in ASD populations. This view is consistent with the general treatment of contextualized thinking in the mainstream literature on autism. Typically, within this literature, contextualized thinking is presented as an adaptive and inherent ability to integrate relevant information in order to derive meaning. Incoming stimuli tend to be contextualized in order to derive a meaningful gist of the situation, often at the expense of surface details (Frith, 1989). However, individuals with ASD are presented as having either a tendency not to integrate all available knowledge (e.g. Happé & Frith, 2006) or an inability to do so (e.g. Just, Cherkassky, Keller & Minshew, 2004) resulting in a lack of contextualized processing.

The next chapter explores possible processes underlying a tendency not to integrate information, relating to inner speech and working memory. Recent experimental findings suggest that individuals with ASD may differ from typical populations in their use of inner speech in problem solving. There is some evidence that individuals with ASD make less use of inner speech compared to typical groups when engaged in a number of problem solving tasks (Whitehouse, Maybery & Durkin, 2006; Maybery, Whitehouse, Durkin & Comerford, 2007).

At the same time theories about how disparate areas of the brain interact to integrate information focuses on the role of inner speech, as a means of combining and broadcasting information across distinct modules (Carruthers, 2002; 2009). Bringing together such work, results in the hypothesis that a tendency not to use inner speech may be related to a lack of integration of information exhibited by individuals with ASD. The final studies of the thesis, outlined in Chapter 5, investigate this hypothesis.

Chapter 5

Introduction

Chapters 3 and 4 indicate that individuals with ASD make less use of background knowledge in reasoning about the world, compared to typical controls. This proposal is supported by a number of previous studies (See Happé & Frith, 2006) which demonstrate that individuals with autism have a tendency not to process incoming stimuli in context. The assertion that individuals with autism tend not to integrate all available information is arguably descriptive. Previous work seeking to explain a lack of contextualised processing has focused largely on the tendency to rely on piecemeal rather than holistic processing (Frith 1989, 2003) and a number of neurological studies providing neuroimaging (e.g. Just et al, 2004) and anatomical evidence (e.g. Courchesne et al., 2001; Herbert et al., 2004) for a lack of connectivity between brain regions. Thinking style in autism has been linked not only to enhanced attention to details and reduced central coherence, but also to a tendency to rely on visual rather than verbal processing (e.g. Koshino et al., 2004; Muller et al., 1999). Recently evidence has also emerged that individuals with autism make less use of inner speech during problem solving (Whitehouse, Maybery & Durkin, 2006).

Accounts of the integration of information within the reasoning literature, present complex reasoning tasks as involving explicit thought processes which are limited by working memory, and are realised in natural language sentences (Evans & Over, 1996; Frankish, 2004). Other accounts go beyond this, in proposing that language is the medium through which information is integrated (Carruthers, 2002; 2009). Alternative explanations for a lack of contextualised thinking stem from new models of working memory which propose reasoning to be dependent on a domain general sub-component of working memory, serving to bind information from different sources. This chapter will begin to explore, therefore, the

relationship between the integration of background knowledge in conditional reasoning, inner speech and working memory. A wider question deriving from the work presented here is whether reduced inner speech is related to a lack of integrative processing in autism. This work draws upon the reasoning literature, philosophical theories about language, and evidence relating to thought processes among individuals with ASD.

Carruthers (2002; 2009) claims that natural language is the means by which information is integrated in the brain. Carruthers presents a model of the brain as being essentially modular. Input and output modules deal with specific domains such as early visual processing, face recognition or language. In addition, 'central' modules process conceptual information concerned with particular domains such as a naive physics or theory of mind. These central modules are not necessarily linked to particular neural locations, and are not encapsulated in the same sense as peripheral modules such as those processing early visual inputs.

Carruthers draws on archaeological evidence (Mithen, 1996) in proposing that early hominids were not able to integrate diverse information from different domains. The appearance of language and conscious thought coincided with the modern ability to join information across domains in thinking and reasoning about the world. Carruthers claims, therefore, that it is language itself which is the medium of non domain specific thinking. Language serves to integrate information from diverse domain specific modules, and results in the complexity of modern thought processes.

Carruthers (2002) proposes that central conceptual modules take their input from perception, but that their output enters a non domain specific central 'arena'. This arena is manifested in the integration of central inputs through language. All domain general reasoning is realised through language, whether it is conscious or not. Carruthers borrows from Chomsky (1995) in suggesting that language in the central arena is realised in some kind of pre-conscious proto sentences or logical form. Reasoning may be in a rudimentary form, but once it is represented in sentences it becomes conscious. It is only language that can act to

combine the outputs of central modules; this is because it is both an input and an output module. Central modules provide inputs resulting in language production. Once language is produced and attended to, whether it is produced externally or internally, then comprehension processes act to broadcast outputs back to central modules, such as theory of mind. In this way a cyclical dynamic process effectively combines and recombines information across domains. Carruthers proposes a special relationship between language, theory of mind and conscious awareness. Consciousness occurs when language inputs become available to the theory of mind module, hence we are aware of our own inner speech.

Carruthers (2002; 2009) is not claiming that we consciously combine information; in fact he claims that we have no conscious access to our own reasoning and decision making, and we interpret our own conscious thoughts in much the same way as we interpret the speech of others. If we consider the act of reasoning about a given statement, the statement is read and recoded into inner speech. According to Carruthers, comprehension processes then act to broadcast the statement to the central conceptual modules. The outputs of the central modules are combined in the central arena, through proto linguistic forms, resulting in sentences appearing in conscious awareness which relate to the question at hand.

Carruthers is not suggesting, however, that all thought is in the form of inner speech. Thoughts can be visual in nature, but visual thinking relies upon a peripheral module which does not have both input and output capacity. Visual thoughts are not open to comprehension sub-processes in the same way that linguistic thoughts are. Visual thoughts cannot, therefore, serve to integrate information in the same way as inner speech.

Firsthand accounts by people with autism suggest that they rely on visual thought patterns. Temple Grandin (1995), for example, explains her extraordinary capacity for design as resulting from visual thinking. Grandin claims that she thinks in pictures and uses visualisation to work through problems and represent concepts. There is supporting experimental evidence that people with autism may be more reliant on visual rather than verbal processing.

Individuals with autism tend to show particularly good performance on visual search tasks and tasks requiring the analysis of visuo-spatial details, such as the block design assembly subtests of the Wechsler intelligence test (e.g. Tymchuck, Simmons & Neafsey, 1977). Neuroimaging studies (e.g. Koshino et al., 2005) also show unusual levels of activation during executive tasks, in areas associated with visual processing among participants with autism. Typical controls engaged in the same tasks show activation in areas associated with verbal processing.

Individuals with autism also show greater activation in the right hemisphere and posterior brain regions, compared with controls, when engaged in a range of tasks. This pattern of activation has been taken to suggest a reliance on non-verbal processing (e.g. Koshino et al., 2004; Muller et al., 1999).

A somewhat different approach to the role of language in cognition stems from the work of Vygotsky. Vygotsky claimed that inner speech developed from external speech. In young children thought is limited by its preverbal nature. Inner language transforms thought allowing for more complex mental functioning. Vygotsky claimed that the primary role of inner speech was cognitive self-regulation (Vygotsky, 1988). There are a number of studies which suggest that inner speech modulates executive function (e.g. Emerson & Miyake, 2003; Kray, Eber & Lindenberger, 2004; Baldo, Dronkers, Wilkins, Ludy, Raskin & Kim, 2005). There is also a growing body of evidence that children with autism make less use of inner speech on executive tasks.

Whitehouse, Maybery and Durkin (2006) presented children with autism and typical controls with three tasks known to implicate inner speech. Participants were given a verbal recall task presenting both pictures and words. Typically, pictures are easier to recall because they are encoded through both visual and verbal routes. The children with autism showed a lower superiority effect for pictures, compared to controls, suggesting that they did not employ additional verbal encoding. In a second experiment Whitehouse et al. presented an additional recall task where words with either one or many syllables were included. Typically,

shorter words are easier to recall. This effect is known to be related to verbal coding. Participants were presented with verbal and visual representations of words. Where pictures are presented, the word length effect is associated with verbal recoding. The children with autism showed a smaller word length effect in the pictorial condition, compared with controls. Whitehouse et al. claim that both of these experiments suggest a reduced use of inner speech in the group with autism, compared to controls. In a final experiment the children were given a measure of task switching, known to be contingent upon inner speech. Participants were also required to carry out a concurrent task designed to suppress inner speech. Articulatory suppression only affected the typical control group. In this case, therefore, the children with autism were not hindered by the secondary task, and demonstrated better task performance compared to controls. This suggests that the group with autism were employing an effective but atypical processing strategy which did not rely upon inner speech.

Russell, Jarrold and Hood (1999) found intact executive performance in children with autism on tasks which were not dependent on inner speech. They claim that these findings support the view that children with autism tend not to encode rules verbally. As a result, they perform poorly on tasks which require the holding of self-instructional information in working memory, such as arbitrary rule-based executive tasks. On the other hand, the tying up of inner speech will have less effect on children with ASD, compared with typically developing children, on executive tasks which can be approached with non-verbal processing. Russell et al. claim, therefore, that inner speech plays an important role in self-regulation on tasks requiring working memory, the capacity to hold information in mind while performing another mental operation. This proposal is supported by Joseph, McGrath and Tager-Flusberg (2005). This study explored the relationship between language and a number of executive tasks among children with autism. Children with autism were shown to perform poorly on a number of executive tasks, but showed comparable performance to controls where verbal

responding alleviated the need for rehearsal in inner speech. They concluded that performance was related to a lack of verbal self-regulation.

The experiments presented in this chapter aim to investigate whether suppressing inner speech impairs the ability to integrate information in conditional reasoning. The suppression of inner speech has not been shown to affect performance on conditional reasoning problems with arbitrarily related content. There are, however, no previous studies which explore the effect of articulatory suppression on the use of background knowledge in everyday conditional reasoning. Evans and Brooks (1981) presented participants with simple conditional reasoning problems where the content expressed arbitrary relationships between colours and shapes, as in the following example:

Premises: If it is a circle, then it is red

It is a circle

Conclusion: It is red

Participants were given simple concurrent articulatory load (saying the numbers 1-6 repeatedly) or articulatory load with a working memory component (recalling and repeating a different sequence of the numbers 1-6 for each trial). Evans and Brooks found articulatory load did not affect reasoning performance, either with or without additional memory load. They did find a latency effect, however. Reasoning under secondary articulation resulted in faster response times than reasoning with no secondary load. However, this study has been criticised for using a between subjects design. A subsequent study (Toms, Morris & Ward, 1993) repeated the tasks used by Evans and Brooks with a within subjects design. They found that although secondary articulation had no effect on reasoning outcomes, articulation with memory load had a detrimental effect particularly on Modus Tollens (MT). MT ('if p then q, q is false' it follows that 'p is false.') is generally accepted to be a difficult inference to draw, involving the processing of negatives.

The main focus of the studies by Evans and Brooks (1981) and Toms et al. (1993) is the role of working memory in conditional reasoning. The dominant model of working memory referred to in these studies is that of Baddeley (Baddeley & Hitch, 1974; Baddeley, 1986). Baddeley's influential model proposes that working memory is made up of a central processor or executive which acts in conjunction with slave systems providing temporary storage of information. A visuo-spatial scratchpad stores limited amounts of visuo-spatial information in the form of images, and an articulatory loop acts as a temporary store for speech information. Spatial and verbal working memory are dissociable in terms of their respective storage mechanisms. The question of whether the central executive can be compartmentalised into spatial and verbal processing is more controversial, although there is evidence for dissociations between central executive spatial and verbal processing in both children (Jarvis & Gathercole, 2003) and adults (Jurden, 1995; Shah & Miyake, 1996).

Working memory has been implicated in the integration of information through a specific domain general sub-component of the central executive. Recent studies of the nature of working memory have proposed the integration or binding of information from disparate sources as a key function of the central executive (Wheeler & Treisman, 2002; Oberauer, Süß, Wilhelm & Sander, 2007). This binding function has also been specifically linked to the integration of information in reasoning (Halford, Cowan & Andrews, 2007). Baddeley himself has also proposed a new component of the central executive, the episodic buffer (e.g. Baddeley, 2007), which deals specifically with the integration of information across domains. The episodic buffer is presented as a temporary store which is able to integrate information from multiple sources. It is controlled by the central executive which can retrieve information from it in the form of conscious thought or awareness. This information can be further manipulated by the central executive.

Carruthers (1998) does make reference to working memory, and has made parallels between his own model of cognition and Baddeley's model of working memory. He points

out that the integrative capacity of linguistic thought would best be equated with the central executive and the phonological loop, although he would attribute additional functions to the phonological loop, in providing access to our own thoughts and hence allowing for recursive processing. More recently Carruthers (2006; 2009) has also linked his model to dual process accounts where the working memory dependent System 2 is associated with an explicit, conscious reasoning capacity involving natural language.

It seems reasonable to assume that tasks which suppress inner speech would be likely to interfere with Carruthers linguistic integration model. What is less clear, however, is whether interference would result from articulatory suppression alone or whether some involvement of executive processing would be necessary to suppress the integration of information during reasoning. Experiment 5 will, therefore, focus on the use of a secondary articulatory task during conditional reasoning where background knowledge is manipulated. This will be extended in Experiment 6 to include a secondary articulatory load with additional working memory demands.

Given the results of Experiment 1, an observable effect of background knowledge among adolescents with ASD would not be expected. Since it is also the case that little is known about the relationship between inner speech and contextualised reasoning in typical populations, the experiments presented here focus on a typical adult population. It is well established that typical adult populations are influenced by background knowledge during conditional reasoning.

Although participants with ASD were not included in Experiments 5 and 6, all participants were given the Autism Quotient (AQ) Questionnaire (Baron-Cohen, Wheelwright, Skinner, Martin & Clubley, 2001). The AQ is a relatively new instrument designed to measure autistic traits among adults with normal intelligence. Since it has been postulated that autism represents the extreme of a continuum (Baron-Cohen & Hammer, 1997), people within the typical population can have more or less autistic traits reflecting their position on that

continuum. The AQ has also been shown to be a useful screening tool for ASD in identifying individuals who are candidates for full diagnostic assessment (Woodbury-Smith, Robinson, Wheelwright & Baron-Cohen, 2005). The questionnaire is made up of 50 questions assessing 5 areas; social skill, attention switching, attention to detail, communication and imagination (See Appendix A5). These subcategories reflect the triad of symptoms in autism (APA 1994) and known cognitive impairments in autism. High autistic traits are associated with poor social skills, poor communicative skills, exceptional attention to local details, poor attention switching or a strong focus of attention and poor imagination. Each question is in a forced-choice format. Participants must respond by circling 'Definitely agree', 'Slightly agree', 'Slightly disagree' or 'Definitely disagree'. Questions are scored according to numbers of agree or disagree responses. Participants score one point for each response reflecting autistic tendencies.

Although adults within the typical population are known to be influenced by knowledge and belief in conditional reasoning, the results of Experiments 1 and 4 suggest that people with high autistic traits may be less influenced by background knowledge compared to those with low traits. Use of the AQ allows for the investigation of the relationship between autistic traits and the influence of counterexamples, including the contributions of specific categories of traits to reasoning outcomes.

As individuals with autism show less reliance on inner speech, compared to the typical population, it is plausible that people with high autistic traits make less use of inner speech during reasoning. Individuals with high traits may be more dependent on alternative reasoning strategies involving, for example, visual simulation of the presented scenarios or probabilistic judgements not based on explicit counterexample cases. As a result, high trait participants may be less affected by the suppression of inner speech compared to low trait participants.

In Experiment 5, participants were presented with two conditional reasoning tasks one with a concurrent articulatory suppression task and one with a simple tapping task. All

participants were also given a working memory task and the AQ questionnaire. In Experiment 6 all participants were given the same two reasoning tasks as in Experiment 5. One group was given the secondary articulatory and tapping tasks as in the previous experiment. The other group received more complex articulatory and tapping tasks designed to burden working memory. Once again all participants were also given a working memory task and the AQ questionnaire. In line with the findings of Experiments 1 and 4, it was predicted that participants with high traits would show less influence of counterexamples compared to those with low traits. It was also predicted that participants would show less influence of counterexamples under articulatory load compared to tapping and this would be more marked where working memory was also burdened. Suppressing inner speech was also expected to have less influence on the contextualization of reasoning for those participants with high autistic traits.

Experiment 5

The purpose of Experiment 5 was to investigate whether suppressing inner speech would lead to less integration of background knowledge during everyday conditional reasoning. The relationship between working memory capacity, AQ and reasoning outcomes was also explored.

Method

Participants

47 adults took part in the study. The sample included 25 females and 22 males. Participants were recruited through the University of Plymouth participant pool on a paid volunteer basis.

Materials and procedure

All participants were given a conditional reasoning task with a secondary articulatory load, and a conditional reasoning task with a simple tapping load. Participants were also given the autism quotient questionnaire (AQ) designed to measure autistic tendencies (Baron-Cohen et al., 2001) and a measure of working memory based on that developed by Case, Kurland and Goldberg (1982) known as 'The Counting Span Task'. This task incorporates a processing component (counting) and a storage component (remember the number of dots counted) and increases in difficulty over time.

There were two question sets in the reasoning task. All of the questions had been used previously in Experiment 1. Each question set presented 16 MP and 16 AC arguments largely drawn from Cummins, Lubart, Alksnis and Rist (1991). Half of the questions in each set were known to have high levels of available background knowledge in the form of counterexamples, and half were known to have low levels of available counterexamples. The questions were presented on a computer. Participants were presented with brief instructions as follows:

In this task you will be shown some statements. After each statement there will be a fact and a conclusion. Given the statement and the fact, you need to make a decision about whether the conclusion follows.

All questions were presented as a statement, an invitation to suppose a fact, and a question about what follows:

If the ignition key is turned, then the car will start

Suppose that the ignition key is turned,

Does it follow that the car will start?

Participants were required to respond by pressing one of two buttons, labelled 'YES, definitely' and 'NO, not necessarily.'

All participants completed both question sets presented in a random order. In the articulatory condition participants were asked to answer the reasoning questions whilst saying the words 'Monday Tuesday Wednesday Thursday Friday' repeatedly, in time to a metronome. The metronome was set at set at 140 beats per minute, corresponding approximately to the average number of words articulated per minute in natural speech (e.g. Hargie and Dickson, 2003). Since response times were recorded, it was decided to present a control condition which also included a secondary task component with a minimal cognitive load. A simple tapping task was chosen, as previous studies have demonstrated that simple tapping load does not affect conditional reasoning performance (Toms, Morris & Ward, 1993). The simple tapping task required repetitive tapping of 5 keys with one finger, at the same rate as the articulatory task. Reasoning outcomes and response times were recorded for both tasks. All participants were given the AQ questionnaire prior to the experiment, and articulatory and tapping conditions were counterbalanced across participants.

Results

The scores on the AQ questionnaire ranged from 9-36 with a mean score of 18.30. Baron-Cohen et al.(2004) report an average of 16.4 with 80% of individuals with ASD scoring 32 or above. 2 individuals scored above the 32 point cut off. Means, range and standard deviations for each of the AQ subcategories are shown in Table 5.1

For the purposes of analysis a median split was performed on the AQ scores resulting in two groups with high and low autistic traits. The scores on the working memory task were

high with 51% of participants having the maximum span score. This possible ceiling effect suggests that the processing element included in the task may not have been sufficiently challenging for this population. These scores were similarly split with the high working memory group being at ceiling on working memory span.

Table 5.1 Means, range and standard deviations for each subcategory of the AQ

Subcategory	Range	Mean	SD
Social skills	0-9	2.68	2.28
Attention switching	0-8	4.23	1.81
Attention to detail	1-10	5.83	2.33
Communication	0-8	3.00	1.96
Imagination	0-7	2.51	1.80

Mean endorsement responses for the reasoning task with high vs low available disablers on MP and high vs low available alternatives on AC under articulation and tapping are shown in Table 5.2.

Table 5.2 Mean endorsements made by low/high AQ groups for MP and AC varying in availability of counterexamples under articulatory and tapping load in Experiment 5.

		MP				AC			
		Low disablers		High disablers		Low alternatives		High alternatives	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Low AQ	Articulation	3.29	0.95	2.46	1.67	2.70	1.49	1.08	1.35
	Tapping	3.29	0.91	2.71	1.55	2.79	1.35	1.38	1.31
High AQ	Articulation	3.17	0.89	2.61	1.64	2.30	1.55	1.09	1.31
	Tapping	3.35	1.03	2.65	1.47	2.70	1.55	1.13	1.46
Total	Articulation	3.23	0.91	2.53	1.64	2.51	1.52	1.09	1.32
	Tapping	3.32	0.96	2.68	1.49	2.74	1.44	1.26	1.37

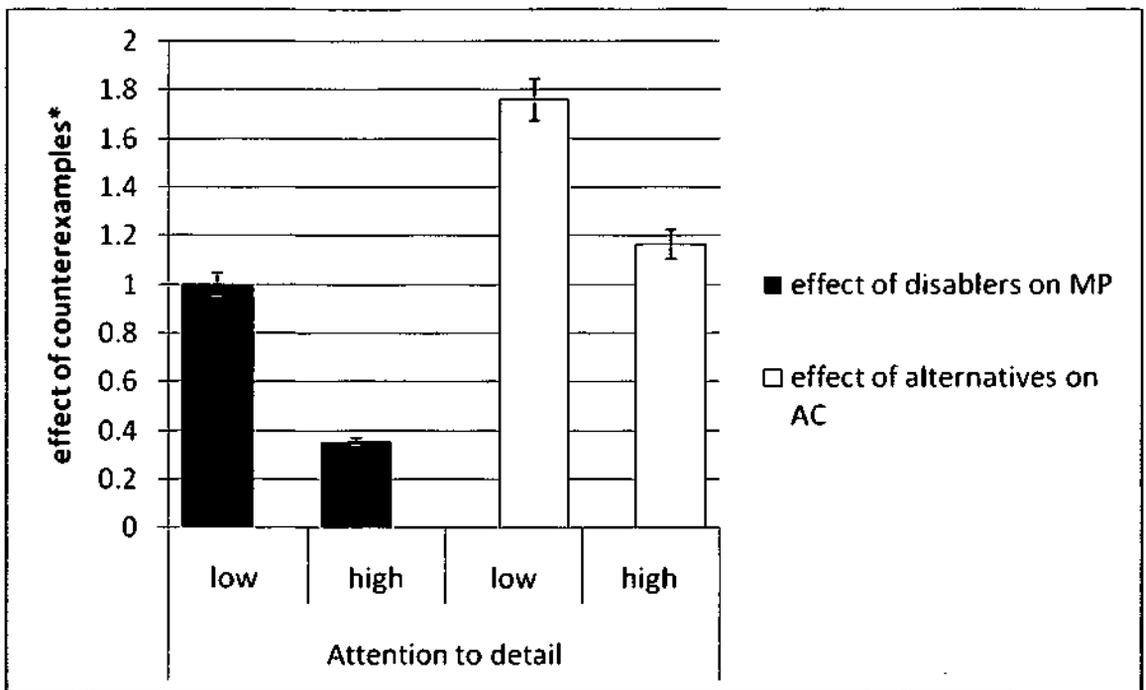
A 2x availability of disabling conditions (high vs low), 2x secondary condition (articulation vs tapping) analysis of variance was carried out on the MP responses. High and low autistic traits were entered as a between subjects factor. Working memory groups were also added as a between subjects factor. The analysis revealed a significant main effect of the availability of disabling conditions ($F(1,43) = 21.85, MSE = 1.19, p < .001, \eta^2_p = .30$) such that participants were more likely to deny the MP inference where there were high numbers of available disabling conditions. There was no significant effect of condition ($F(1,43) = 1.29, MSE = 0.59, p = .26, \eta^2_p = .03$), such that reasoning outcomes did not significantly differ under articulatory compared to tapping load. There were no significant interactions with AQ suggesting that broad AQ traits were unrelated to reasoning outcomes. There were also no significant interactions with working memory, showing that high and low span groups did not significantly differ in the use of background knowledge during reasoning.

A 2x availability of alternative antecedents (high vs low), 2x secondary condition (articulation vs tapping) analysis of variance was carried out on the AC responses. Once again working memory and AQ were entered as between subjects factors. The analysis revealed a significant main effect of the availability of alternative antecedents ($F(1,43) = 87.98, MSE = 1.12, p < .001, \eta^2_p = .67$) such that participants were more likely to deny the AC inference where there were high numbers of available alternatives. There was no significant effect of condition ($F(1,43) = 2.78, MSE = 0.70, p = .10, \eta^2_p = .06$), such that reasoning outcomes did not significantly differ under articulatory compared to tapping load. Once again there was also no significant interactions with working memory or AQ.

The influence of specific autistic traits was explored in more detail through correlation analysis. A measure of the effect of counterexamples was derived by calculating the difference between numbers of endorsements when few and many counterexamples were available. This measure was correlated with scores for each of the AQ subcategories. Analysis revealed a

significant negative correlation between attention to detail and the effect of counterexamples across all conditions $r(47) = -0.30, p = .04$. There were no other significant correlations.

High attention to detail is associated with high autistic traits. Participants were identified as having either high or low attention to detail on the basis of the median score. *t* tests revealed significant differences between participants with high and low attention to detail on the effect of counterexamples measure. This was the case for both MP ($t(45) = 2.11, p = .04$) and AC ($t(45) = 2.05, p = .05$). Participants with high attention to detail were less influenced by counterexamples on both types of inference, as shown in Figure 5.1.



*The effect of counterexamples is the difference between numbers of endorsements where few counterexamples are available and endorsements where many counterexamples are available.

Figure 5.1 The effect of counterexamples across all conditions for low and high attention to detail groups.

Further analysis was carried out on the response times for the reasoning questions.

Response times for MP and AC inferences are shown in Table 5.3. An analysis of variance was performed on the response times for all inferences, 2x inference type (MP vs. AC) 2x condition (articulation vs. tapping) with autistic trait groups as a between subjects factor. Analysis revealed a main effect of condition ($F(1,45) = 28.23, MSE = 30.13, p < .001, \eta^2_p = .39$) such that response times were significantly higher for tapping compared to articulatory secondary loads. A significant interaction was also revealed between inference type and condition ($F(1,45) = 4.09, MSE = 14.03, p = .05, \eta^2_p = .08$) such that the difference between response times for articulation and tapping was more marked for MP. There was also a significant two-way interaction between condition and autistic traits ($F(1,45) = 5.94, MSE = 30.13, p = .02, \eta^2_p = .12$).

Table 5.3 Mean response times in milliseconds for MP and AC inferences under tapping and articulatory secondary load for Experiment 5.

	MP		AC	
	Mean RT (ms)	SD	Mean RT (ms)	SD
Articulation	7313	4759	7936	4993
Tapping	12627	9861	11050	7948

Follow up t tests revealed that the difference in response times between tapping and articulation was significant for groups with both high autistic traits ($t(23) = 3.37 p = .003$) and with low autistic traits ($t(22) = 4.22 p = < .001$). The difference between tapping and articulation response times was also significantly greater for those with the lowest autistic tendencies compared to those with high autistic tendencies ($t(45) = 2.06 p = .05$) Mean response times across all inferences under articulation were 7737ms (SD=5014) for low AQ participants and 7518ms (SD=3991) for high AQ participants. Mean response times across all

inferences under tapping were 13944ms (SD=7051) for the low AQ group and 9821ms (SD=4356) for the high AQ group (see Figure 5.2).

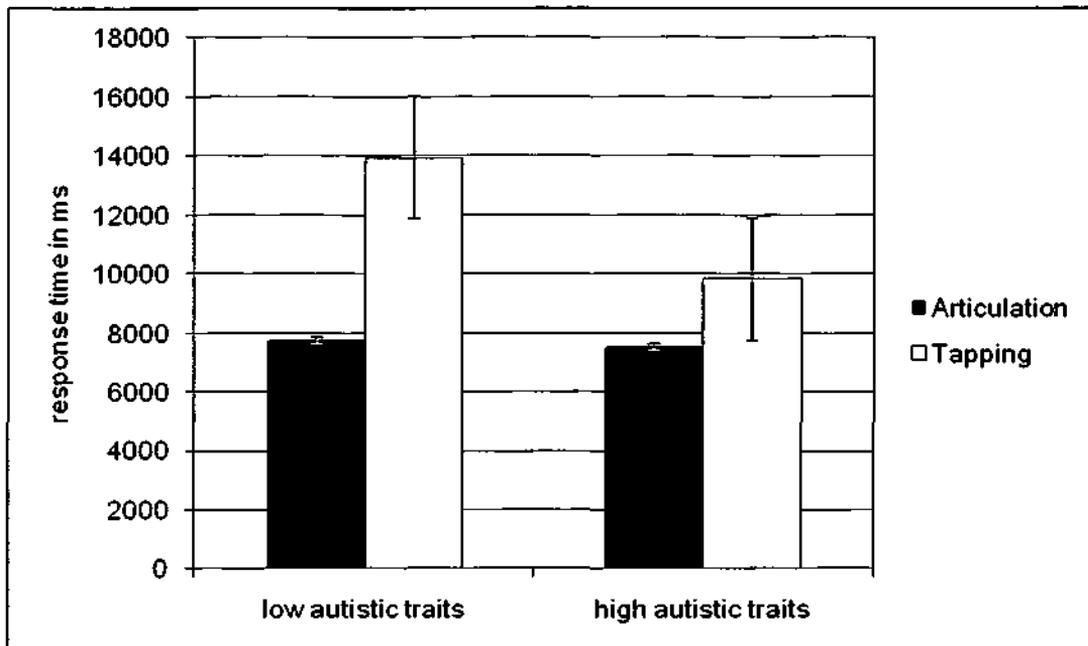


Figure 5.2 Mean response times for all inferences under articulation and tapping load for groups with high and low autistic traits in Experiment 5.

Discussion

Articulatory secondary load was not found to affect reasoning outcomes in Experiment 5, for either MP or AC inferences. Where disabling conditions and alternative antecedents were available, participants were influenced by background knowledge and showed the typical pattern of responding. Disabling conditions acted to increase the tendency to deny the MP inference, and alternatives acted to reduce endorsements of AC. This was found to be the case under secondary articulatory load and simple tapping. These results are in line with previous studies of conditional reasoning with arbitrarily related material. (Evans & Brooks, 1981; Toms et al. 1993). This finding suggests that the integration of background knowledge with presented material is not affected by articulatory suppression.

The prediction that the influence of background knowledge on reasoning outcomes would be related to AQ scores was not supported. The effect of counterexamples on reasoning was found to be significantly related, however, to the attention to detail subcategory of AQ. Those participants with high attention to detail showed less influence of counterexamples compared to those with low attention to detail. Attention to detail is also referred to as attention to local details (Baron-Cohen et al., 2001) and is taken here to reflect weak central coherence in autism. Previous studies also show that the AQ attention to detail subcategory is significantly correlated with measures of weak central coherence, including local processing tasks such as the Embedded Figures task (Grinter, Van Beek, Maybery & Badcock, 2008) and global processing tasks such as context effects on speech perception (Hui-Chun & Ota, 2007). Attention to detail questions can, therefore, be seen to assess the degree to which a person is a local or a global processor. As weak central coherence accounts would predict, a local processing style is associated with less integration of background knowledge during reasoning. These results hence support the findings of Experiments 1 and 4 which show that individuals with autism tend not to integrate all available knowledge during reasoning.

Although reasoning outcomes were unaffected by articulatory suppression, response times were significantly longer for simple tapping compared to articulation. This finding is interesting in the light of the work of Evans and Brooks (1981) who found that reasoning under secondary articulation resulted in faster response times than reasoning with no secondary load. Neither the Evans and Brooks study nor the work presented here show that response times under articulation are related to any deficit in performance. The present data differ somewhat from that of Evans and Brooks, as a measure of autistic traits was included. For groups with low and high autistic traits the response times do not differ for articulatory load. It is rather the case that both groups take longer to respond under simple tapping, and that this effect is significantly more marked in the individuals with low autistic traits. It is possible that simple tapping slows participants down, although this is unlikely given that

previous studies show no effect of simple tapping on conditional reasoning performance or latencies (Toms et al. 1993). It is perhaps more likely, that where participants are free to engage in inner speech, in the simple condition, they spend longer reflecting on the problem. Hence reflection appears to spontaneously take place, but thinking about the problem does not ultimately influence reasoning outcomes. There is evidence that introspection does not include consideration of underlying reasoning processes (e.g. Evans, 1996) and that people's reports of their inner trains of thought during reasoning actually reflect confabulations (Evans, 1989; Wason & Evans, 1975; Carruthers, 2008). The reported findings support this account, as inner speech appears to be peripheral to the actual reasoning taking place.

The difference in response times between articulation and simple tapping is more marked among those participants with low autistic traits. This implies that those with higher autistic traits spend less time spontaneously thinking about reasoning problems. This finding raises the possibility that a reduced reliance on inner speech may be related to autistic traits, shared by those diagnosed with ASD and members of the general population.

Overall, these findings suggest that the production of inner speech alone is not related to the integration of information in reasoning. It may be, however, that integrative processes make use of central working memory components. In the previous study by Toms et al. (1993), although secondary articulation was not found to influence reasoning performance, articulation with a working memory load had a detrimental effect, specifically on MT.

Working memory has also been implicated in conditional reasoning with everyday content. De Neys, Schaeken and d'Ydewalle (2005) investigated the effect on everyday conditional inference of a secondary complex tapping task with a working memory component. For low working memory span participants, the concurrent task led to less integration of background knowledge for all inferences. For those with high working memory, this effect was specific to invalid inferences. Verschueren, Schaeken and d'Ydewalle (2005) presented participants with a think aloud conditional reasoning task under working memory preload. Participants had to

memorize dot patterns, and hold these in mind during the reasoning task. Analysis of the answers given revealed that working memory preload decreased reliance on counterexample information. Working memory preload also increased acceptance of all inferences, even where there were large numbers of available counterexamples. Verschueren et al. claim that preload can, in some cases, result in a disregard for all background knowledge and reliance on a simple matching heuristic.

Previous studies suggest that working memory load may affect reasoning performance whether that load has an articulatory element or not. These studies differed from the design presented here, however, as the Toms et al. (1993) study used arbitrary material where the integration of background knowledge was not relevant for task performance. The Verschueren et al. (2005) study employed a preload, rather than secondary load task, and both this study and that of DeNeys et al (2005) employed a spatial working memory task load. The possibility that a working memory load would affect the integration of background information in conditional reasoning was explored in Experiment 6. Any effect was further defined by including both spatial and articulatory secondary working memory loads.

Experiment 6

The purpose of Experiment 6 was to investigate the effect of working memory load on reasoning outcomes. Experiment 6 also allowed for comparison of reasoning performance under simple and complex loads with verbal or spatial content.

Method

Participants

The participants for Experiment 6 were 87 undergraduate students from the University of Plymouth. Participants were enrolled on a points as reward system. There were 56 female and 31 male participants.

Materials and procedure

Half of the participants were given a conditional reasoning task with a secondary simple articulatory load and a conditional reasoning task with a simple tapping load, as presented in Experiment 5. The other half of the participants were given the same two reasoning tasks. One reasoning task was presented with a concurrent complex articulation task, and the other was presented with a complex tapping task. In the complex articulation task participants were presented with the words 'Monday, Tuesday, Wednesday, Thursday, Friday' on a computer screen. The words appeared in a mixed up order before each reasoning trial. Participants were required to repeat the words in the given order, then press a continue button. They had to remember the order of the words, and repeat the words in that order for the duration of the trial until a new sequence of the words appeared. Participants were instructed to say the words in time to a metronome set at 140 beats per minute.

In the complex tapping task a different sequence of 5 keys lit up on a 3x3 button box before each reasoning trial. The keys stayed lit up during the first sequence tapped by the participants. They were required to remember the sequence and continue tapping for the duration of the reasoning trial. Participants were instructed to tap the keys in time to a metronome, set, once again, at 140 beats per minute.

Participants were also given the AQ questionnaire used in Experiment 5. All participants completed the AQ questionnaire prior to the other experimental tasks. Since many

participants seemed to be at ceiling on the Counting Span task used in Experiment 5, an alternative working memory measure was employed, the operation span (OSPAN) (Turner & Engle, 1989). This version of the OSPAN was presented on a computer and participants had to maintain words for later recall while solving arithmetic problems. Reasoning and working memory tasks, as well as articulatory and tapping conditions, were counterbalanced across participants.

Results

The scores on the AQ questionnaire ranged from 5-26 with a mean score of 14.12. Means, standard deviation and range for each of the AQ subcategories are shown in Table 5.4.

Table 5.4 Means, range and standard deviations for each subcategory of the AQ for participants in simple and complex conditions.

	Subcategory	Range	Mean	SD
Simple condition	Social skills	0-5	1.09	1.16
	Attention switching	1-9	4.50	1.58
	Attention to detail	0-8	4.66	2.14
	Communication	0-4	2.09	1.39
	Imagination	0-6	1.98	1.36
Complex condition	Social skills	0-5	1.41	1.33
	Attention switching	1-8	4.42	1.72
	Attention to detail	0-9	4.49	2.15
	Communication	0-7	2.21	1.66
	Imagination	0-7	1.67	1.41

Mean endorsements for the simple and complex conditions under articulation and tapping are shown in Table 5.5.

A 2x availability of disablers, 2 x condition (articulation/tapping) analysis of variance was performed on the MP data with type of load (simple/complex) as a between subjects factor. Analysis revealed a main effect of the availability of disabling conditions ($F(1,85) = 35.91$, $MSE = 0.55$, $p < .001$, $\eta^2_p = .30$) Such that there was a general effect of disablers on reasoning performance regardless of load (see Figure 5.3). Participants with low and high AQ and working memory scores were identified on the basis of the median. No significant effects or interactions were revealed when working memory and autistic traits were entered as between subjects factors.

Table 5.5 Mean endorsements for MP and AC varying in availability of counterexamples under simple and complex articulatory and tapping load in Experiment 6.

		MP				AC			
		Disabling conditions				Alternative antecedents			
		Low		High		Low		High	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Simple condition	Articulation	3.65	0.65	3.05	1.23	3.05	0.97	1.53	1.49
	Tapping	3.40	1.03	3.00	1.27	3.33	1.27	1.40	1.38
Complex condition	Articulation	3.39	0.89	2.84	1.36	3.00	1.28	1.82	1.57
	Tapping	3.52	0.70	3.16	1.05	3.16	1.24	1.91	1.55

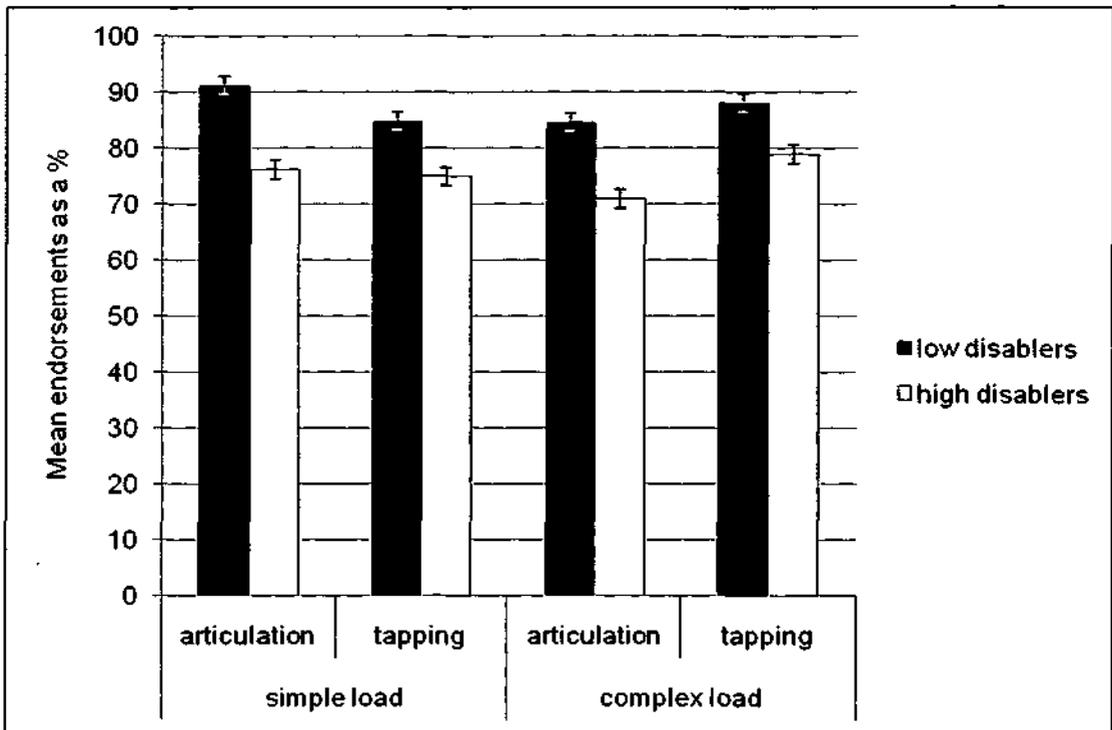


Figure 5.3 Mean endorsements for MP with low and high available disabling conditions under simple and complex articulatory and tapping loads in Experiment 6.

Further analysis was carried out on the reasoning responses to AC questions. A 2x availability of alternatives (low/high), 2x condition (articulation/tapping) analysis of variance was performed with type of load (simple/complex) as a between subjects factor. A significant main effect of availability of alternatives ($F(1,85) = 143.83, MSE = 1.30, p < .001, \eta^2_p = .63$) was revealed and a significant interaction between the availability of alternatives and load (simple v complex) ($F(1,85) = 4.25, MSE = 1.30, p = .04, \eta^2_p = .05$) such that the effect of background knowledge on reasoning outcomes was reduced under complex load (see Figure 5.4). No significant effects or interactions with autistic traits or working memory span were revealed when entered as between subjects factors.

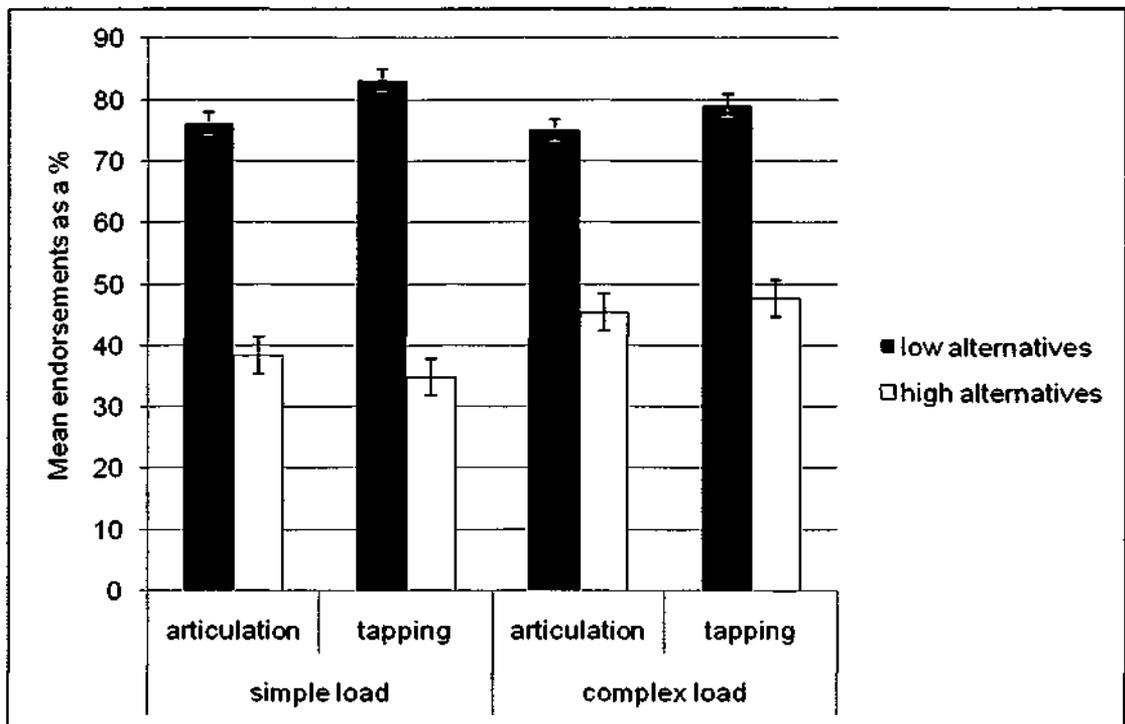


Figure 5.4 Mean endorsements of AC with low and high available alternatives under simple and complex articulatory or tapping load in Experiment 6.

A measure of the influence of counterexamples was created by calculating the difference between numbers of endorsements when few and many counterexamples were available. The effect of counterexamples measure was correlated with scores for each of the AQ subcategories. Analysis revealed no significant correlations for the participants in the simple condition. There was a significant negative correlation, however, between attention to detail and the effect of counterexamples in the complex condition $r(47) = -0.26, p = .05$. Since the complex task was designed to load working memory, a moderated regression analysis was performed to explore the contributions of both working memory and attention to detail on the effect of counterexamples. Moderated regression added something to the initial correlational analysis here as, unlike Experiment 5, there were two distinct predictors. The regression analysis allowed for the examination of interaction between these predictors as continuous variables. The results are summarised in Table 5.6.

Table 5.6 Summary of Moderated Regression analysis for variables predicting the effect of counterexamples on reasoning outcomes

Predictors	<i>B</i>	<i>SEB</i>	β
Attention to detail	-.134	.052	-.375*
Working Memory	.001	.011	.012
Attention to detail x Working Memory	-.014	.005	-.428**

Note $R^2 = .24$. Attention to detail and Working Memory were centered at their means.

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

Analysis indicated a moderating influence of working memory on attention to detail, as a predictor of the effect of counterexamples. The fact that the beta coefficient is negative demonstrates that among this group, high attention to detail is associated with low influence of counterexamples. The beta coefficient for the linear regression between attention to detail and endorsements also indicates an independent influence of attention to detail on performance (See Table 5.6) Means for the influence of counterexamples in the complex condition, for groups with low vs high working memory and low vs high attention to detail are shown in Table 5.7.

Table 5.7 Means and standard deviations for the influence of counterexamples in the complex condition, for low/high working memory and low/high attention to detail

Working memory capacity	AQ Attention to detail	Mean	SD
low	low	0.92	0.88
	high	0.56	0.73
high	low	1.55	0.74
	high	0.63	0.53

Additional analysis was carried out on the response times for all inferences. A 2x inference type (MP/AC) 2x availability of counterexamples (low/high) 2x condition (articulation/tapping) analysis of variance was carried out with type of load (simple/complex) as a between subjects factor. The analysis revealed a significant main effect of type of load ($F(1,85) = 4.10, MSE = 44.22, p = .05, \eta^2_p = .05$) such that response times were longer for complex load compared to simple load. No significant effects were found when working memory and AQ were entered as between subjects factors.

Further analysis was carried out on the response time data from the simple condition alone, in order to establish whether the findings from Experiment 5 were replicated. A 2x inference type (MP vs. AC) 2x condition (articulation vs. tapping) analysis of variance was performed with autistic trait groups as a between subjects factor. Analysis revealed a main effect of condition approaching significance ($F(1,42) = 3.24, MSE = 12.66, p = .08, \eta^2_p = .07$) such that response times were higher for tapping compared with articulatory secondary loads. There was also a main effect of AQ ($F(1,42) = 5.80, MSE = 9.89, p = .02, \eta^2_p = .12$) such that response times were longer overall for participants with low autistic traits.

Discussion

In Experiment 6, participants were less influenced by counterexamples under working memory load. This effect was particular to the invalid inference AC. For the valid inference MP, working memory load did not significantly reduce the influence of background knowledge on reasoning responses. This pattern of results is partly in line with those of DeNeys et al. (2005) who found that a complex spatial load lessened the influence of counterexamples on AC for all participants, but increased the the effect of counterexamples on MP for those with very high working memory capacity. DeNeys et al suggest that this finding is related to the ability of high working memory participants to inhibit disabling conditions where they are not deemed relevant. Working memory load is taken to interfere with this inhibitory process.

The effect of working memory load on AC was found across both articulatory and spatial secondary tasks. This suggests that the integration of background knowledge is related to domain general working memory processes and is not specifically related to inner speech.

As in Experiment 5, in the simple condition participants with low AQ scores spent longer thinking about the reasoning problems. In Experiment 6 this appeared to be the case regardless of type of load. In both Experiment 5 and the simple condition of Experiment 6 longer latencies were not related to reasoning performance.

In the complex condition, attention to detail predicted the degree to which participants were influenced by background knowledge. This relationship was moderated by working memory capacity. As in Experiment 5, piecemeal processing was associated with less influence of background knowledge on reasoning.

In Experiment 6 the mean AQ score was lower than in Experiment 5 and there were no participants who exceeded the 32 point cut off for ASD. In fact, the highest AQ score in the simple condition was only 23. As shown in Tables 5.1 and 5.4, maximum scores on the subcategory attention to detail were also lower in Experiment 6 compared to Experiment 5.

The fact that the influence of counterexamples was related to attention to detail in Experiment 5, but not in the simple condition of Experiment 6 may reflect a lack of high AQ scorers in Experiment 6.

General Discussion

The results of Experiment 5 showed that the influence of background knowledge on reasoning was unaffected by the suppression of inner speech, on both valid and invalid inferences. Response times in both experiments were found to be longer under simple tapping compared to a articulation. In Experiment 5, this finding was specific to those participants with low autistic traits, This result was partly replicated in Experiment 6 where participants with low autistic traits showed longer latencies overall. Experiment 6 showed that working memory load lessened the effect of background knowledge on reasoning outcomes, this effect was particular to invalid inferences. Further results showed that the effect of working memory load was significant across both spatial and articulatory complex load. Response times were also shown to increase under complex load compared to simple load. In Experiment 5 and the complex condition in Experiment 6 there was a significant inverse relationship between the AQ subcategory, attention to detail, and the influence of background knowledge on reasoning. In Experiment 6 this relationship was moderated by working memory. This finding was not replicated in the simple condition of Experiment 6, although mean scores for attention to detail were lower among this group, with maximum scores being well below the 32 point cut off for ASD.

Overall the findings presented here do not support Carruther's (2002; 2009) claim that the integration of information in cognition is dependent upon inner speech. The results of Experiment 5 and 6 showed that reasoning response times varied for articulatory and simple tapping load. Response times were longer under tapping compared to articulation. This difference in latency was not related to reasoning outcomes. These findings suggest that the

processes involved in everyday conditional reasoning are not dependent on the use of inner speech. Under the simple control condition participants were free to spend time thinking about the problem. This was not the case in the articulatory condition, where inner speech was suppressed. Hence inner speech appears to spontaneously occur, but additional thinking time does not impact on reasoning performance. There is additional evidence that thinking about a problem does not reflect underlying reasoning processes (e.g. Evans, 1996). It has, therefore, been proposed that thinking during conditional reasoning is involved with the justification of choices made, and serves no purpose within the reasoning process itself (Evans, 1996; 1989; Wason & Evans, 1975). The findings presented here add additional evidence to the claim that inner speech during conditional reasoning reflects confabulation.

The results of Experiments 5 and 6 suggest that thinking style may have some bearing on the use of inner speech during reasoning. In Experiment 5, those participants who had low autistic traits spent more time thinking about the problem where they were free to do so. Those who had higher autistic traits showed no significant difference, however, in the times taken to respond to reasoning questions, whether inner speech was suppressed or not. This finding was partly replicated in Experiment 6 where low AQ scores were associated with longer latencies overall. These findings add support to previous studies which show that individuals with autism make less use of inner speech in a number of problem solving tasks (e.g. Whitehouse et al., 2006) and also extends these findings to the wider population.

Experiment 5 and Experiment 6 indicate that the integration of background knowledge during reasoning is related to the attention to detail subcategory of the AQ. High AQ scores are known to be related to poor performance on tasks requiring the integration of information for higher meaning, such as combining visual information into coherent wholes (Grinter, Maybery, Van Beek, Pellicano, Badcock & Badcock, 2009). The subcategory, attention to detail, is also significantly correlated with tasks taken to measure local (Grinter, Van Beek, Maybery & Badcock, 2008) and global processing (Hui-Chun & Ota, 2007). Low attention to

detail is, therefore, associated with integrative processing whereas high attention to detail is associated with piecemeal processing. The findings presented here indicate that a lack of influence of background knowledge during conditional reasoning is associated with just one AQ trait. This finding adds support to the results of Experiments 1-4 which indicated that an absent or weak influence of background knowledge was due to a failure to integrate counterexample information.

Where cognitive demands are very high, the relationship between attention to detail and the influence of background knowledge is moderated by working memory capacity. As discussed previously, individuals with low working memory capacity, including young children also tend not to integrate all available information during reasoning, especially where representational demands are high. Across previous experiments, participants have been matched on standard working memory scores so differences in the influence of counterexamples are not attributable to working memory capacity per se. Since participants with ASD have extreme attention to detail, however, they are likely to apply a piecemeal processing strategy which may overload available resources. This is demonstrated more clearly among the typical population where there is more variation in attention to detail scores (See Table 5.7). Hence, in Experiment 6 where processing demands were very high, the participants with low working memory and high attention to detail show the lowest effect of counterexamples, whilst those with high working memory and low attention to detail show the highest. Attention to detail also independently predicted influence of background knowledge in Experiment 6 and it is unclear whether individuals with high piecemeal processing scores fail to draw together information in working memory due to a strong processing choice or an inability to do so.

The development of the AQ has facilitated the study of autistic traits within the typical population. Such studies show that many of the tendencies associated with autism are also found in the wider population among those with high autistic traits (e.g. Stewart, Watson,

Allcock & Yaqoob, 2009; Grinter et al., 2009). The findings presented here add to those studies, in showing that a reduced influence of background knowledge during reasoning is found among individuals with high attention to detail within the broader autism phenotype as well as among individuals diagnosed with ASD. Hence, in the studies presented here, both the adolescents with autism in Experiments 1 and 4 and adults from the typical population with high attention to detail show less influence of counterexamples on reasoning outcomes.

The fact that the integration of background knowledge was suppressed by both spatial and articulatory working memory load suggests that a domain general component of working memory is implicated in the integration of counterexamples in conditional reasoning. This finding supports a model (Oberauer et al., 2007) where working memory plays a central role in integrating information, and this role is not specifically reliant on either verbal or spatial storage mechanisms. This model is incompatible with traditional models of working memory which propose primary functions to be processing and storage of domain specific information (Baddeley & Hitch, 1974; Baddeley, 1986). According to the account, principally put forward by Oberauer and colleagues (Oberauer et al. 2007; Oberauer, Süß, Wilhelm & Wittmann, 2008), the primary purpose of working memory is to integrate information and create new temporary relational representations. These representations are necessary for performance on a variety of complex tasks including text comprehension and reasoning. Oberauer et al. (2008) found that relational integration was highly correlated with reasoning performance. According to this account, reasoning relies on the creation of complex models similar to situation models taken to underlie text comprehension (e.g. Zwaan & Radvansky, 1998). Such models include not only the binding of elements from disparate domains together, but also the integration and maintenance of a number of relational combinations (Halford, Wilson & Phillips, 1998). The fact that reasoning response times were longer under complex spatial and articulatory load compared to simple load further suggests that interference was affecting a domain general rather than a specific language based component of working memory.

Interestingly Oberauer also points to the necessity of binding in a number of everyday tasks such as

“‘seeing’ a constellation in a collection of stars.’ Oberauer et al. 2008 (pg 641)

reminiscent of the typical drive to bring details together to create meaningful wholes described by accounts of central coherence (Frith 1989). It is exactly this kind of relational representation that individuals with autism appear not to rely upon. Oberauer et al. (2008) also suggest that this binding function is capacity limited. Hence the ability to integrate information is not a question of all or nothing, but is dependent, to some degree, on capacity and task complexity.

The results of Experiment 6 show a similar pattern to those of DeNeys et al. (2005). In this study conditional reasoning problems were presented with a concurrent complex tapping load with a working memory component. They also found a reduced affect of background knowledge under load. Participants with low working memory span showed this effect across both valid and invalid inferences. For high span participants this was limited to invalid inferences. For the high span group the effect of disabling conditions on reasoning outcomes under load increased. DeNeys et al. suggest that the lack of an effect of load on MP reflects a cancelling out of effect across high and low spans. High span participants are sensitive to the logical validity of MP and MT and consequently tend to inhibit background knowledge in favour of logical argument. Working memory load suppresses inhibitory capabilities, however, hence the influence of background knowledge increases.

The results of the final two experiments raise intriguing questions regarding the relationship between new formulations of working memory involving relational integration, and a lack of integrative processing in individuals with ASD. These questions raise possibilities for future study outside of the scope of this thesis. The implications of the findings presented

in this chapter will be explored, with reference to the findings of the previous experiments, as part of the main discussion which forms the next chapter.

Chapter 6

Discussion

The studies presented in this thesis explore contextualized reasoning predominantly among adolescents with ASD compared to typical control groups. This work draws on two distinct literatures referring to the effect of knowledge and belief on reasoning in typical populations and information processing among individuals with autism. Both of these literatures are concerned with the processing of information in context. A number of accounts of autism, including weak central coherence (Frith, 1989), underconnectivity theory (Just et al., 2004) and complex processing deficit theory (Minshew et al., 1997), propose that individuals with autism have a tendency not to integrate background information for higher meaning. Reasoning within the typical population has also been extensively explored with regard to the influence of background knowledge. In everyday life, reasoning on the basis of knowledge and belief is an adaptive human drive which helps us to deal flexibly with a range of situations. This drive typically results in the consideration of all available information in reasoning about the world (Evans, 2007).

The combination of these two literatures led to the hypothesis that individuals with ASD would be less influenced by background knowledge in everyday reasoning. Contextualized conditional reasoning was chosen to test this hypothesis for a number of reasons: first there is substantial previous knowledge regarding performance on conditional reasoning tasks among typical participants, secondly everyday conditional reasoning is known to be influenced by a specific kind of background knowledge in the form of counterexamples, thirdly previous work has shown a robust effect of background knowledge on conditional reasoning outcomes for both typical adolescent and adult populations (e.g. Markovits & Janveau-Brennan, 1999; Cummins, 1995; Thompson, 1994).

Overall the findings of the thesis show that adolescents with ASD are less influenced by background knowledge compared to typically developing adolescents when engaged in conditional reasoning with everyday content. The findings also strongly suggest that a lack of contextualized reasoning is due to a weak or absent tendency to integrate information among adolescents with ASD. These results add to knowledge about information processing in autism by exploring a previously understudied domain.

In order to establish whether the reasoning results were attributable to a lack of integrative processing, a number of tasks were presented exploring other explanatory possibilities. Although adolescents with autism tend not to integrate background information during conditional reasoning, they show an ability to draw information together in simpler tasks. Performance on these tasks offers some insight into the mixed findings associated with weak central coherence.

In the final two experiments typical participants with a local processing style show less influence of counterexamples in conditional reasoning, compared to those with a global processing style. The typical participants also show less influence of background knowledge in conditional reasoning when working memory is overburdened. These results add support to models which claim that integrating information is a core function of working memory. These findings are also of interest in the light of late processing accounts of autism, which claim that cognitive overload may play a role in processing difficulties.

Findings relating to the weak central coherence account of autism

In Experiment 1, the adolescents with ASD show significantly less influence of background knowledge during everyday conditional reasoning compared to typical controls. Typically developing adolescents display the customary effect of both disabling conditions and alternative causes. For the typical group, available counterexamples in the form of disabling conditions lead to a significant drop in acceptance rates for MP. Where counterexamples in

the form of alternative causes are available there is a significant increase in uncertainty responses to AC. The participants with ASD, however, are significantly less influenced by counterexamples on both the valid inference MP and the invalid inference AC. This pattern of performance is not associated with individual differences in expressive vocabulary, inhibition or working memory. These results cannot be explained by differences in logical reasoning ability, since background knowledge acts to discourage logical reasoning on valid inferences and encourage logical reasoning on invalid inferences. The group with ASD also show similar logical performance to the typically developing adolescents where few counterexamples are available.

This work supports previous findings falling broadly within the weak central coherence account of autism, which show that individuals with autism tend not to process stimuli in context. This processing style is demonstrated in a failure to use sentence context to disambiguate homographs (Frith & Snowling 1983; Happé 1994), reduced wholistic processing of faces (Teunisse & De Gelder, 2003), a reduced ability to identify pictures from visual fragments (Booth, 2006) and a lack of inference on the basis of context in short stories (Jolliffe & Baron-Cohen, 2000).

Weak central coherence accounts propose a failure to process stimuli in context deriving from an absence of the drive to draw information together for higher meaning. According to this account, individuals with autism will not contextualize their reasoning due to a tendency not to integrate available information. There are, however, a number of other possible explanations. The likelihood judgment task and the subsequent experiments outlined below investigated whether the results from Experiment 1 can be explained by a simple response bias, differences in underlying beliefs or differences in background knowledge available to the two participant groups.

The likelihood judgement task in Experiment 1 required participants to rate their belief in the statements used in the reasoning task. As well as the explicit consideration of

counterexample cases, implicit information about the believability of the premises has been shown to influence reasoning outcomes (e.g. Lui, Lo & Wu, 1996; Oaksford, Chater & Larkin, 2000, Evans, Handley & Over, 2003; Weidenfield, Oberauer & Hornig, 2005). The likelihood judgment task explored whether underlying beliefs about the content of the reasoning statements differed for the group with ASD compared with controls. The results of this task show that the adolescents with ASD do not differ from controls in likelihood ratings of the reasoning statements. Hence the likelihood judgement task eliminates the possibility that the results of Experiment 1 are due to differing underlying beliefs about the information in the premises.

Further explanations for the results of Experiment 1 are explored in Chapter 4. Experiment 2 investigated whether adolescents with ASD exhibit a yes response bias. The customary effect of background knowledge is to reduce 'yes' responses for both MP and AC. An apparent lack of influence of counterexamples on reasoning performance among the group with ASD could, therefore, reflect a yes response bias. Previous studies of contrary-to-fact reasoning have found evidence for an affirmative response bias among younger children with autism (Leevers & Harris, 2000). The problems presented in Experiment 2 have a similar structure to those used by Leevers and Harris, but with factual content. The participants with ASD do not significantly differ from typical controls in the responses given to these materials, however, and they show no difference in their willingness to give 'no' responses.

The findings of Experiment 1 could also be explained by differences in the background knowledge available to the two groups. Experiment 2 investigated whether participants with ASD generate similar numbers and types of counterexamples to controls in response to rules and facts derived from the materials used in Experiment 1. The results show that the two groups do not significantly differ in either the number or types of counterexamples generated. The adolescents with ASD, therefore, have comparable information available to them, and are able to retrieve that information when prompted to do so.

Although adolescents with ASD are able to generate counterexamples when instructed to do so, it does not follow necessarily that they can spontaneously generate background knowledge during the reasoning process. Experiment 4 actively provided participants with information referring to counterexample cases in order to explore whether all available information was integrated during reasoning. This experiment specifically relates, therefore, to the weak central coherence claim that a failure to process information in context is the result of a weak or absent drive to integrate information. The Suppression Task (Byrne, 1989) was used, as it allows for the presentation of an extra premise: a second conditional statement which directly prompts consideration of a counterexample. Extra premises were presented in the form of additional and alternative arguments.

According to the principal theoretical account of the Suppression Task (Byrne, 1989; Byrne, Espino & Santamaria, 1999), underlying reasoning mechanisms depend on models which represent the world as if the premises were true. The presentation of the extra premise calls the conclusion derived from such a model into question by bringing counterexamples to mind. Where the extra premise is an additional argument antecedents and consequents are combined conjointly, as in the following example:

If Mary has an essay to write, then she will study late in the library

If the library stays open, then Mary will study late in the library

(Mary will study late in the library if she has an essay to write **and** the library is open).

Where the extra premise is an alternative argument antecedents and consequents are combined disjointly, as shown below:

If Mary has an essay to write, then she will study late in the library

If she has a textbook to read, then she will study late in the library

(Mary may have an essay to write **or** she may have a textbook to read).

Typical performance on the suppression task relies, therefore, on the integration of presented contextual information with existing models of the premises. Processing will also involve

background knowledge to some extent, as reasoners need to recognise that the extra premise refers to a counterexample case. In considering the additional argument presented above, for example, participants need to infer that libraries can only be accessed when they are open. Therefore, Mary cannot study in the library if it is shut. This task differs from that presented in Experiment 1, however, as the extra premise alleviates the need to spontaneously generate explicit counterexample cases.

The adolescents with ASD show significantly less effect of contextual information on reasoning outcomes in this task compared to controls, even though specific cues referring to counterexample cases are provided. It is reasonable to assume, therefore, that reasoning performance among the adolescents with ASD reflects a tendency not to integrate available background information.

The findings of the first four experiments add support to the weak central coherence account of autism in demonstrating that adolescents with ASD show less influence of background knowledge in reasoning. As suggested by the weak central coherence account, adolescents with ASD show a weak or absent tendency to integrate all available information in order to reason in context. The work presented here clearly adds to the known domains in which individuals with autism show weak central coherence.

The AQ and the integration of background information in the wider population
In Experiments 5 and 6 adult participants from the typical population were given the Autism Quotient questionnaire (Baron-Cohen et al., 2001) as a measure of autistic traits. The AQ is designed to measure autistic traits among adults with normal intelligence. The AQ has been presented as a useful screening tool for ASD in identifying individuals who are candidates for full diagnostic assessment (Woodbury-Smith, et al., 2005). The questionnaire assesses social skill, attention switching, attention to detail, communication and imagination. These subcategories reflect the triad of symptoms in autism (APA 1994) and known cognitive

impairments in autism. High autistic traits are associated with poor social skills, poor communicative skills, exceptional attention to local details, poor attention switching and poor imagination.

Experiments 5 and 6 explored the roles of language and working memory in the integration of background information during conditional reasoning. Both experiments employed secondary tasks designed to burden inner speech, and in the case of Experiment 6 also working memory whilst solving conditional reasoning tasks. The results relating to secondary task load will be discussed further in a later section. Since Experiments 1 and 4 show that adolescents with ASD tend not to integrate background knowledge during reasoning it was predicted that individuals in the wider population with high autistic traits would also be less influenced by contextual information.

Experiments 5 and 6 show that overall AQ scores are not related to reasoning performance, but scores on the attention to detail subcomponent are significantly correlated with the degree to which reasoning is influenced by available counterexamples. In Experiment 5 those participants with high attention to detail scores show significantly less influence of available background information, compared to those with low scores. This is partly replicated in Experiment 6. In the complex condition where secondary load had a working memory component, once again, participants with high attention to detail show less influence of background knowledge, this relationship is also mediated by working memory scores.

The attention to detail subcomponent of the AQ is shown to be related to weak central coherence. Attention to detail is significantly correlated with measures of weak central coherence, including local processing measures such as the Embedded Figures Task (Grinter et al., 2008) and global processing tasks such as context effects on speech perception (Hui-Chun & Ota, 2007). Attention to detail questions can be seen as assessing the degree to which a person is a local or a global processor. As weak central coherence theory predicts, Experiments 5 and 6 show that a local processing style, with a high attention to detail, is

associated with less integration of relevant information during conditional reasoning. These findings extend those of Experiments 1 and 4 in demonstrating that a particular autistic trait is predictive of the degree to which an individual will be influenced by available contextual material. These results also add weight to the conclusion that among individuals with ASD a tendency not to take account of background knowledge during conditional reasoning is due to a failure to integrate all relevant information.

The AQ is a relatively new measure, but existing studies show that many autistic tendencies are also found among individuals in the wider population with high autistic traits (e.g. Stewart et al., 2009; Grinter et al., 2009). Individuals who score highly on the AQ, and are identified as potentially having autism, show high attention to detail in combination with a pattern of poor social and communicative skills, poor attention switching and poor imagination. In the wider population individuals may present very different patterns, scoring highly on the attention to detail subcomponent, for example, but having good social or attention switching skills. The AQ may, therefore, be useful in assessing which autistic traits are associated with atypical performance on a number of tasks.

Individuals with Asperger syndrome and high functioning autism score significantly higher on the AQ than individuals in the wider population (Baron-Cohen et al., 2001). The measure was designed as a brief tool for identifying levels of autistic traits in the general population and as a potential screening tool for further diagnosis of autism. It seems to work well for these purposes (e.g. Woodbury-Smith et al., 2005). As we have seen, measures of weak central coherence such as the Embedded Figures Task are significantly correlated with attention to detail. Further work is needed, however, to establish that scores on all subcomponents of the AQ are meaningful as distinct measures. It may be that the AQ subcomponents present a useful starting point for assessing which traits are implicated in particular tasks. Nevertheless, the AQ is a self report questionnaire and as such is open to general criticisms of measures of this type. The questions are closed and, therefore, limit the responses available to participants.

For some individuals results may also reflect what participants erroneously believe to be true about themselves or what they may wish to present to the experimenter.

In both Experiment 5 and Experiment 6 mean scores for the attention to detail component are higher than mean scores for any other subcomponent. Examination of Baron-Cohen et al's. (2005) original wide-ranging study shows similar patterns. With the exception of the group with Asperger syndrome or high functioning autism, who necessarily scored highly across the board, all other groups show higher mean scores for attention to detail compared to other categories. It may be that high attention to detail is relatively common in the wider population compared to other autistic traits. Alternatively these findings may reflect the nature of the participants recruited. In the Baron-Cohen et al. study participants included mathematicians, scientists, olympiads and students. Nevertheless, Baron-Cohen et al. did have a group of randomly selected controls and participants in Experiment 5, reported here, were from a voluntary participant pool. These participants also show high scores on this subcomponent.

The findings of Experiments 5 and 6, along with Experiments 1 and 4 strongly suggest that individuals with autism fail to take account of background knowledge due to a lack of integrative processing. Recent reappraisals of weak central coherence, however, (Happé & Frith, 2006; Happé & Booth, 2008) have highlighted mixed results with regard to the ability of individuals with autism to integrate information. Individuals with autism seem able to draw information together to arrive at meaningful outcomes in some cases. Although the adolescents with ASD in the present studies tend not to integrate information during conditional reasoning, they do show the ability to combine information in a number of the other tasks. These results will be discussed in the next section.

Findings reflecting mixed results associated with weak central coherence

The findings presented here show that adolescents with ASD are able to draw together information to derive meaning in certain circumstances. In Experiment 1, for example, where background knowledge is not available both groups show similar reasoning outcomes and levels of logical performance. This means that the adolescents with ASD are able to integrate information presented in the premises to arrive at reasoning responses. Both groups also show similar patterns of performance on the simple reasoning task used in Experiment 2 to assess a possible yes response bias. Furthermore, the group with ASD demonstrates similar performance compared to controls in generating counterexamples when prompted to do so, and in deriving a degree of a belief in the conditionals presented. Both of these tasks require the generation of background knowledge, in the light of given material, in order to achieve meaningful outcomes. These tasks are, however, intrinsically less complex than contextualised conditional reasoning. Both involve specific prompts to retrieve background knowledge. These tasks also involve the activation of a response without further manipulation. The reasoning tasks in Experiment 1 and Experiment 4 involve either the spontaneous activation of background information, or the activation of background knowledge in response to explicit cues referring to counterexample cases. This knowledge must then be further integrated and manipulated with information presented within the premises.

Within the weak central coherence literature there are also mixed results showing that people with autism can integrate information for higher meaning in specific cases. Individuals with autism can, for example, integrate information about a given object or routine (Ameli, Courchesne, Lincoln, Kaufman, & Grillon, 1988; Pring & Hermelin, 1993). Happé and Frith, (2006) suggest that connecting information in these tasks depends upon item to item associations or chaining. Integrating information within a single domain may also be intact; individuals with autism are able, for example, to draw together information relating to calendrical calculations. (Heavey, 2003). There is also evidence that people with autism can

attend to global features when they receive explicit prompts to do so, as in the hierarchical figures task, for example (Plaisted, Swettenham & Rees, 1999).

Conflicting results in the ability of individuals with autism to process information in context are not reflected in studies of enhanced local processing where results are more consistent (Happé & Frith, 2006). This has resulted in a recognition that enhanced local processing and weak global coherence do not necessarily go hand-in-hand (e.g. Reyna and Kiernan, 1994; Burack, Enns, Iarocci & Randolph, 2000; Porporino, Shore, Iarocci & Burack, 2004). An enhanced piecemeal processing style has, therefore, been emphasized as a core ability in autism. A lack of global processing has been played down to some degree, and is conceptualized as a tendency rather than a deficit. At the same time, there is a retrospective acknowledgement that previous studies have conflated poor global coherence with good local processing abilities, hence good performance on the Embedded Figures Task, for example, has been taken as evidence for weak central coherence (Happé & Booth, 2008).

The mixed findings related to processing in context have been explained with reference to the modality of the task at hand. Lopez and Leekam (2003), claim that individuals with ASD have a specific problem with processing verbal information in context. This account draws on the finding that people with autism do not show impairments in contextualised processing in a number of visuo-spatial tasks including Navon tasks or visual illusions tasks (E.g. Ozonoff, Strayer, McMahon, & Filloux, 1994; Ropar & Mitchell, 1999), but do demonstrate difficulties processing complex verbal information in context (e.g. Frith & Snowling, 1983; Jolliffe & Baron-Cohen, 1999).

The results of the experiments reported here do not support the account presented by Lopez and Leekham (2003), since there is no reason to believe that the verbal nature of these tasks is responsible for the information processing difficulties experienced by participants with ASD. Although both the likelihood judgment task and the conditional reasoning task are verbal in nature and use materials with the same content, the adolescents with autism show

similar performance to controls on one task and not the other. It appears that it is the complexity of the task at hand and the degree to which it is effortful in nature which are the relevant factors. In both the generation task and the likelihood judgment tasks participants were specifically prompted to retrieve background knowledge but to make no further use of it. Performance on these tasks did not differentiate between the two groups. In the reasoning tasks, however, the typical tendency to integrate contextual information was weak or absent in the ASD group. Since these participants were matched for working memory capacity it seems likely that they were able to hold presented information in mind as well as information activated by the context. What they apparently did not do was to engage in the effortful processing required to integrate this contextual information with their reasoning.

Previous studies of the nature of probabilistic judgment show that underlying processes are implicit in nature (Evans & Over, 1997; Oaksford & Chater, 2001). Probabilistic judgments and the explicit consideration of background information both draw on the same knowledge base, but the nature of the contextual information is very different. Everyday conditional reasoning typically involves available examples being brought to mind. Integration and manipulation of these examples is limited by executive resources and is effortful in nature. Probabilistic judgment, on the other hand, is not dependent on cognitive resources (Verschueren, Schaeken & d'Ydewalle, 2005).

Both weak central coherence and complex processing deficit accounts provide additional evidence for specific difficulties relating to the effortful integration of information. Within the vast literature related to weak central coherence, perhaps the most relevant work to this discussion concerns text comprehension in autism. Aspects of reading appear to be intact, but individuals with autism have difficulty using context in reading and generally appreciating the meaning of texts (e.g. Frith and Snowling, 1983; Happe', 1997). This difficulty is typically explained with reference to central coherence and a tendency not to integrate information. Available studies support the work presented here in demonstrating a specific processing

problem relating to the effortful integration of explicit background information with online presented material.

Saldana and Frith (2007) explored the possibility that text comprehension difficulties in autism lie at an automatic level of processing. They employed a task known to tap the use of implicit bridging inferences in text comprehension (Singer & Halldorson, 1996). Bridging inferences allow for information to be filled in which is not actually stated in the text. Their results show, however, that individuals with autism are able to make implicit inferences when reading short texts. They found a strong priming effect of such inferences on the speed with which subsequent questions were answered by participants with autism and controls. Saldana and Frith show that readers with autism are able to draw on implicit processes involving world knowledge in order to arrive at inferences which influence subsequent responses. Saldana and Frith conclude that the problems in text comprehension exhibited by individuals with autism lie at a higher processing level.

Other studies of text comprehension in autism focus on effortful processes. Individuals with autism show impairment in integrating presented information with explicitly available contextual information in order to arrive at ongoing deep text comprehension (Joliffe and Baron-Cohen, 1999; 2000). This deficit is demonstrated in a variety of tasks. Individuals with autism fail to use context to interpret ambiguous sentences (Joliffe and Baron-Cohen 1999), or to integrate sentence information with a theme in order to arrange sentences coherently. They also fail to integrate story information to arrive at global inferences which allow for the accurate interpretation of character actions (Joliffe and Baron-Cohen, 2000). Participants with autism demonstrate some implicit level of text comprehension, however, in answering questions about the text requiring basic bridging inferences and using temporal cues to arrange sentences.

Joliffe and Baron-Cohen (1999; 2000) claim their findings reflect a difficulty in achieving global coherence, or making causal connections between disparate information in order to

arrive at local, then higher level chunks of contextualised meaning. In this case, global coherence is related to the creation of a situation model. Such models require the integration of information at several levels. Zwaan and Radvansky (1998) for example, make parallels between text comprehension and problem solving in describing the complex interplay between explicit and implicit processes. Causal links are made on the basis of background knowledge and presented material, this results in the creation of an integrated model which is instigated by the search for meaning in any narrative across modalities. This model is described as being implicit in focus, but is constantly updated by integrating the current model in working memory.

The kind of situation models necessary for complex contextualised reasoning or text comprehension require implicit processes, but also the effortful manipulation and integration of the outcomes of such processes with other information. Information from a range of sources is rapidly drawn together, including basic linguistic information, semantics, empirical knowledge, non-linguistic information and external cues (Hagoort & Berkum, 2007).

It seems that individuals with autism are able to make implicit inferences and link information together in order to engage in aspects of text comprehension. What they fail to do is to integrate resulting representations with other information. The findings of this thesis also show that adolescents with autism can draw upon implicit processes and engage in simple inference. They can also activate background knowledge, particularly when cued to do so. As with text comprehension, however, when engaged in contextualised reasoning the adolescents with ASD do not create integrated representations informed by all available information.

The work of Joliffe and Baron-Cohen (2000) shows particular parallels with the results of Experiment 4. In the suppression task we presented participants with explicit prompts referring to counterexample information. Similarly Joliffe and Baron-Cohen actively provided contextual information relating to story themes. In both cases, the individuals with autism tend not to integrate contextual information.

Accounts of text comprehension and contextualised reasoning refer to the creation of integrative models. There is evidence that models supporting contextualized reasoning are similar in nature to situation models in that they are necessarily informationally rich. Such models reflect complex interaction between stimuli and context encompassing a range of types of knowledge about counterexamples, probabilities, causal relationships and temporal order (Handley & Feeney, 2007). The creation of integrative models in reasoning and text comprehension is dependent on effortful processes for the dynamic integration of a range of inputs, including the results of implicit processing. A tendency not to integrate all relevant information implies that individuals with autism will not form complex models of this type.

Much of the evidence from studies of text comprehension refers to effortful and implicit processes. Individuals with autism show comparable performance to controls on tasks requiring predominantly implicit processing, but poor performance compared to controls on tasks which rely on the effortful integration of information. In the reasoning literature such distinctions are generally explained with reference to dual process theories, as discussed in Chapter 2. The next section will explore, therefore, how dual process theories of reasoning can help to describe the mixed results on tasks requiring the integration of information among individuals with ASD.

Dual process theory and the integration of information in autism

Dual process theories propose that there are two cognitive systems or types of processing in the brain. System 1 is fast, unconscious, associative and implicit in nature. System 2 is slow, sequential, effortful and related to conscious intentions. Dual process theory is relevant to the proposal that individuals with autism have a specific tendency not to engage in the effortful integration of information. Such a tendency is specifically associated with System 2.

According to dual process accounts, cognitive ability is relevant to the sequential nature of System 2, and can be described as the limiting capacity of that system. Recently there has been

some agreement that System 1 is actually a collection of systems (Stanovich, 2004; Evans, 2006). These systems all operate in response to stimuli without recourse to the cognitive capacity of System 2. Any task requiring working memory will, therefore, involve System 2. System 2 is fed, however, by content from a variety of implicit systems (Evans, 2009). Combinations of systems result in temporary networks which are realised in differing connections between neural regions of the brain, depending on the task at hand (Goel, 2007).

In real life, decisions are often made on the basis of automatic or habitual System 1 responses. System 2 provides a different kind of thinking, one which is unique to human beings and allows us to think hypothetically about a range of possibilities. Hypothetical simulations allow for thought processes divorced from what is known about the world. Equally, however, effortful contextualised reasoning involves System 2 resources. Dual process theory thus accounts for both the ability to reason logically whilst inhibiting belief but also reasoning on the basis of explicit background knowledge.

Dual process theory implies that there are different kinds of knowledge which can act to influence behaviour. System 1 draws upon implicit knowledge and habitual routines whereas System 2 applies explicit knowledge to contextualise thought processes (Evans, 2009). The outcomes of System 1 processes are available to us in the recognition, for example, that we believe or disbelieve a given statement. This kind of input to System 2 is distinct, however, from knowledge about specific examples drawn from explicit memory.

Dual process theories provide a framework for understanding the influence of different kinds of knowledge and differing levels of processing complexity involved in conditional reasoning. Implicit knowledge about the degree of connection between antecedent and consequent reflected in likelihood judgment tasks has been shown to influence conditional reasoning outcomes. Such judgments are not dependent on working memory resources and as such involve System 1. On the other hand the active consideration of specific counterexample cases is working memory dependent (Verschuere et al., 2005). Dual process theory

consequently suggests that an ability to derive belief in a given statement but an inability to reason on the basis of counterexamples implies a specific System 2 difficulty.

Further relevant definitions of the components of System 2 are provided by Stanovich (2009). According to Stanovich, System 2 involves three levels of processing. The simplest level involves serial associative cognition. This is a form of shallow processing that does not involve the creation of complex hypothetical models. Rather processing involves associative cognition on the basis of information provided to the individual. Such processing makes minimal cognitive demands. Stanovich's ideas are of interest here in relation to item to item associations or chaining as a means of explaining why individuals with autism may be able to link explicit information in order to arrive at calendrical representations, or derive simple inferences on the basis of presented material.

At a higher level of processing, what Stanovich refers to as the algorithmic mind is responsible for hypothetical models requiring the representation of possibilities. Hypothetical representations must be maintained apart from the actual state of the world. Such processing is necessarily dependent on cognitive capacity to some degree. Differing demands are associated with the complexity of the task involved. As discussed, the consideration of possibilities prompted by counterexample cases and the integration of those possibilities with presented information involve such models. The effortful integration of information lacking among individuals with autism is, therefore, associated with algorithmic level function.

Stanovich's final level of System 2 processing is also of interest, as it highlights the role of thinking dispositions in reasoning outcomes. The reflective mind is responsible for activating the algorithmic mind in response to task demands mediated by the goals, motivations and thinking disposition of the individual. Evidence for the existence of the reflective mind includes studies demonstrating additional variance in reasoning performance attributable to thinking dispositions after cognitive capacity has been accounted for (e.g. Bruine de Bruin et al., 2007; Toplak & Stanovich, 2002, 2003). Measures of thinking disposition include

dimensions such as absolutism, willingness to perspective switch, willingness to decontextualise and the tendency to consider alternative opinions (e.g., Stanovich & West 1998a). These dimensions are typically investigated as possible predictors of the tendency to inhibit background knowledge in reasoning tasks. In such cases, the influence of background knowledge is regarded as a bias. These tasks have a different emphasis to the reasoning tasks used here. The task used in Experiment 1, for example, explored the influence of background knowledge rather than the ability to suppress it. As we have seen, in everyday reasoning there is an inherent drive to consider all relevant knowledge among typical populations. Dispositions reflecting a willingness to decontextualise, for example, are consequently not relevant to this task. Among the individuals with ASD, however, this drive appears to be weak or absent. In this case, a willingness *to* contextualise is relevant.

As outlined in a previous section, the mixed findings associated with global coherence in autism have led Happe´ and Frith (2006) to suggest that a failure to take account of context is due to a bias rather than a deficit. Studies which show that individuals with autism are able to take account of the bigger picture when instructed to do so support this claim. Snowling and Frith (1986), for example, found that the usual failure of children with autism to disambiguate homographs on the basis of context was removed when participants were first instructed in the nature of homographs, and the need to identify one of two possible meanings. Happe´ and Frith suggest that individuals with autism employ a piecemeal processing style, which means they tend not to draw information together. It is possible that this processing approach can be overridden with effort, in some circumstances. This is in opposition to the view of reasoning among the typical population, as being characterised by a primary tendency to reason in context which is difficult to suppress.

On the basis of Stanovich's model, whether individuals choose to employ effort to reason in a particular way is dependent on the reflective mind. Individuals with autism whose thinking disposition reflects an unwillingness to contextualise will not send out a call for the

algorithmic mind to be brought online. Stanovich's work, therefore, provides a potential framework for understanding the role of thinking dispositions on task performance in autism. For example, disposition may help to explain instances where individuals with autism draw information together only when instructed to do so.

Dual process theories imply that the integration of representations associated with complex reasoning tasks necessarily depends on working memory. The results of Experiment 6 and the work of De Neys et al. (2005), discussed in the previous chapter, also show that the integration of background information during conditional reasoning is dependent on working memory resources. Recent models of working memory propose that a central function involves the integration of information from different sources. These models will be explored in the next section with reference to the findings under discussion.

Working Memory and integration

Stating that individuals with autism have a specific difficulty with the integration of information during reasoning is to some degree descriptive. Experiments 5 and 6 explored why such a difficulty might arise. Carruthers (2002) proposes that the integration of information from disparate sources is reliant on inner speech. Individuals with autism show less use of inner speech in problem solving compared to controls (Whitehouse et al., 2006). Reduced inner speech could, therefore, potentially explain a lack of integrative processing in autism. On the other hand, recent models of working memory (Oberauer et al., 2007; Oberauer et al., 2008) claim that a central, domain-general function serves to integrate information. This integrative function is specifically implicated in complex reasoning tasks. Experiments 5 and 6 explored the role of language and working memory in the integration of background knowledge in reasoning among typical adults.

Experiment 5 investigated the role of inner speech in integrating information during conditional reasoning. The results of Experiment 5 show that burdening inner speech does not affect the integration of background knowledge during reasoning. Participants engage in more inner speech where they are free to do so, as in the simple control condition. Increased thinking has no effect, however, on reasoning outcomes. These findings were replicated in Experiment 6. In Experiment 5 longer latencies implying more inner speech were specific to those participants with low autistic traits. This finding was also partly replicated in the simple condition of Experiment 6, showing longer latencies overall for participants with low autistic traits.

Experiment 6 investigated the role of working memory in integrative processes by presenting reasoning problems with a secondary verbal and spatial working memory load. Under working memory load, participants show less influence of background knowledge. This effect is particular to AC and is consistent across both verbal and spatial working memory load.

In Experiment 5 and the complex condition of Experiment 6 the influence of background knowledge is associated with the attention to detail subcomponent of the AQ. Those participants with a local processing style, with a high attention to detail, show less influence of background knowledge during reasoning. In Experiment 6, where cognitive demands are high, this relationship is mediated by working memory capacity. The participants with low working memory and high attention to detail show the lowest effect of counterexamples, whilst those with high working memory and low attention to detail show the highest. These findings suggests that reasoning in context is related to the processing style of the individual, the demands of the task at hand and the cognitive resources available.

The findings of Experiment 6 reflect previous work which shows that loading working memory acts to suppress the integration of background knowledge, but also interferes with inhibitory processes (DeNeys et al., 2005). People with very high working memory tend to

inhibit background knowledge in favour of logical responding on valid inferences. Tying up inhibition results in a greater influence of background knowledge, therefore, for a sub-group of participants. For this reason the effects of working memory load are clearer in the case of invalid inferences where no such confound is evident. The results of Experiment 6 show that working memory plays a domain general role in the integration of background knowledge during conditional reasoning. Integrative processes do not rely specifically on verbal working memory resources.

The consideration of counterexamples during conditional reasoning is an effortful process which draws upon cognitive resources (De Neys, Schaeken & d'Ydewalle, 2005). Recent accounts of working memory claim that the integration of information is a central function. According to these accounts a particular component of working memory is involved in the integration of information in complex tasks such as reasoning (Oberauer et al. 2007; Oberauer, et al., 2008). The sub-component of working memory responsible for integration is domain general, and can act on information from a range of sources. Experiment 6 supports this claim; results show that the integration of information in everyday conditional reasoning is dependent on working memory resources which are not specifically verbal or spatial in focus.

Studies exploring working memory show evidence for poor performance compared to typical controls among both adults and children with autism (Luna, Minshew, Garver, Lazar, Thulborn, Eddy & Sweeney, 2002). Other studies conclude, however, that individuals with autism do not have impairment in working memory (Ozonoff & Strayer, 2001). The results presented here show no significant differences in either working memory capacity or measures of inhibition between the groups with ASD and typical controls. Possible reasons for mixed findings in the literature include the fact that individuals with autism present atypical neural networks associated with working memory (Koshino et al., 2005; Koshino, Kana, Keller, Cherkassky, Minshew & Just, 2008). Such networks may signify compensatory mechanisms which allow for good performance in some cases. Traditional concepts of working memory

which focus on processing and domain specific storage sub-components may not reflect core functions associated with the integration of information. Since traditional models of working memory do not focus on integrative function, performance on tasks based on such models may also fail to effectively show specific processing difficulties associated with integration.

Oberauer and colleagues (Oberauer et al., 2007; Oberauer et al., 2008) propose that a central function of working memory is to integrate information and create new temporary representational bindings. These representations underlie performance on a variety of complex tasks including text comprehension and reasoning. Other accounts of working memory have also changed over time to account for the integration of material from different sources. Baddeley's traditional processing and storage model of working memory has been updated to include an 'episodic buffer' (Baddeley, 2000) which is responsible for the integration of information across domains. The episodic buffer is presented as a temporary store which is able to integrate information from multiple sources.

Working memory capacity has been repeatedly shown to be a good predictor of reasoning ability (For a review see Ackerman, Beier, & Boyle, 2005). Oberauer and colleagues (Oberauer et al., 2007; Oberauer et al., 2008) claim that it is the sub-component concerned with 'relational integration' which is predominantly related to performance on complex reasoning tasks requiring the drawing together of information to create new relational structures.

The traditional processing and storage functions of working memory are highly correlated with, but distinct from, relational integration (Oberauer, Süß, Wilhelm, & Wittmann, 2003). This relational integration factor is strongly related to reasoning ability (Oberauer et al., 2008). The brain has a limited ability to hold multiple relational models simultaneously (Wheeler & Treisman, 2002) and consequently the sub-component responsible for relational integration is defined by available capacity. Reasoning is dependent upon the representation of relations between elements, and the manipulation of those relations. Everyday reasoning presents a complex web of relations similar to those posed by situational models used to describe text

comprehension processes. Reasoners must not only combine elements from the premises themselves in temporary structures, but must also incorporate contextual information including background knowledge and external cues. Relational integration is a good predictor of complex tasks such as reasoning or text comprehension without the need for storage or processing factors (Oberauer et al., 2008; Colom, Rebollo, Abad, & Shih, 2006).

Oberauer and colleagues (Oberauer et al., 2007; Oberauer et al., 2008) are not claiming that other tasks do not make use of processing and storage sub-components just that relational integration is a core function relevant to many complex tasks. It is also important to note that a distinction is made between individual bindings and complex models requiring the manipulation of several bindings. It is not the creation and storage of relational bindings that requires this integrative sub-component; it is the integration of those relational structures with other relational structures. This distinction refers to levels of complexity, and is relevant to the results of the likelihood judgment and generation tasks. Both of these tasks require the drawing together of information, since knowledge must be retrieved which is relevant to presented material. Nevertheless, these tasks do not involve the kind of relational complexity needed to reason in context.

Evidence from neuroimaging studies shows that individuals with autism may have atypical large scale brain networks, poor connectivity and compensatory patterns of neural activation between frontal areas and other areas of the brain (e.g. Koshino et al., 2005; Just et al., 2004). Such studies suggest that the typical circuitry involved in complex effortful tasks involving working memory resources may be unusually deployed in individuals with autism.

Neuroimaging studies show that areas of the brain associated with working memory include frontal and posterior cortical regions depending on the type of information being processed and the demands of the task involved. The integration of information from different sources is particularly associated with the frontal cortex including, for example, the left inferior frontal gyrus which is implicated in the integration of linguistic information (Hagoort, 2005), and the

right frontal cortex which is implicated in the domain-general integration of information in working memory (Prabhakaran, Narayanan, Zhao & Gabrieli, 2000). Prabhakaran et al. found relational integration in working memory to be associated with the right prefrontal region. Integrative processing in this area included verbal material but was distinct from left prefrontal regions which only showed involvement in verbal tasks, and posterior cortical regions associated with non-integrative processing and maintenance of information.

It would be premature to suggest that people with autism necessarily have a specific impairment in a sub-component of working memory. This is a subject which raises interesting questions and requires further study. Working memory is, of course, only a construct and a lack of relational integration may better be described by taking a broader view of neural connectivity. Oberauer and colleague's model of working memory is useful, however, in providing a means of conceptualising the differing demands of given tasks in terms of implicit and effortful processing and levels of task complexity. These ideas may go some way to providing clearer definitions of the ability of individuals with autism to engage in some tasks requiring the integration of information but not others.

Complex processing deficit accounts of autism claim that working memory overload is a primary cause of poor performance on complex tasks among individuals with autism. Such overload results from a tendency not to integrate information to create supportive models and schemas. Complex processing deficit theory refers to underconnectivity between cortical regions in autism as underlying integrative difficulties. The next section will explore aspects of the complex processing account, and evidence of neural underconnectivity among individuals with autism which are relevant to the findings under discussion.

Working memory and accounts of autism: complex processing and underconnectivity

Integrative difficulties are proposed to underlie a complex processing deficit in autism (Minshew, Goldstein & Siegel, 1997; Minshew & Goldstein, 2001; Williams, Goldstein & Minshew, 2006). According to Minshew and colleagues, a difficulty in drawing information together, in order to create concepts and schemas, means that incoming information cannot be processed with the support of a contextual framework. This impairment is only apparent in tasks which draw on limited working memory resources. Less complex tasks, or those which generally make fewer demands on cognitive resources, will be unimpaired. Minshew and colleagues argue, therefore, that individuals with autism have difficulties with late processing and a reliance on lower level or early processing, due to poor connectivity between different regions of the brain.

Supporting the account given here of a specific System 2 difficulty, Minshew and colleagues demonstrate impairment with effortful processing across a number of domains including motor skills, memory and language, among both adults (Minshew et al. 1997) and children (Williams et al. 2006). Such evidence relies upon demonstrating lower level competence but higher level incompetence in any given domain. In many cases this lower/higher level dichotomy can be mapped onto System 1 and System 2 processes. For example, Minshew et al. (1997) found impairment in a range of complex language tests including the Reading Comprehension subtest from the Kaufman-Test of Educational Achievement, the Verbal Absurdities subtest from the Stanford-Binet Intelligence Scale and the Token Test. These tests explore complex higher order features of language involving executive dependent coordinating processes such as text comprehension, verbal problem solving, and the comprehension of complex grammatical constructions. At the same time intact simple language processing is demonstrated by performance on WAIS-R Vocabulary

test, K-TEA Reading Decoding task and the Controlled Oral Word Association (FAS) task. All of which rely on implicit associative processes.

Minshew, Meyer and Goldstein (2002) describe a similar distinction in the domain of abstract reasoning between concept identification and concept formation. Individuals with autism are able to identify, learn rules and act upon them, but are unable to draw together information in order to generate concepts to deal with novel situations. Poor performance is shown on tasks requiring concept formation such as the Stanford-Binet absurdities subtests, the 20 Questions task, and the Goldstein-Scheerer Object Sorting task, contrasting with good performance on more simple tasks testing concept identification such as the Halstead Category Test and the Trail Making Test Part B.

The complex processing deficit model has parallels with weak central coherence theory in acknowledging a core ability in autism to be a detail based processing style. Both accounts also recognise a tendency, not to draw information together to create supportive models or gists of a situation. The complex processing deficit account highlights the need for such supportive frameworks to alleviate the demands of complex tasks on working memory resources.

A piecemeal processing approach serves well enough where cognitive demands are not high, but without the top down support provided by integrative models, more complex tasks can rapidly overload available resources. This account can explain why the contextualised conditional reasoning task, which has been shown to be related to cognitive ability (Verschuere et al. 2004), presents difficulties for the group with ASD, but less demanding tasks, such as the generation of counterexamples or the likelihood judgment task, do not. Importantly, however, the adolescents with ASD and controls did not significantly differ on standard measures of working memory, and Minshew and colleagues are not claiming that individuals with ASD have a problem with cognitive capacity per se. A piecemeal processing approach without top down supportive mechanisms results, however, in overwhelming demands on working memory resources in response to complex tasks.

This account is relevant when considering the results of Experiment 6. In the complex condition typical participants were given two concurrent tasks in order to overburden working memory. As expected, those participants with a local processing style show less influence of background knowledge compared to global processors, this relationship was also mediated by working memory capacity. Hence, in a very demanding task those participants with low available cognitive resources and a strong local processing style show the least influence of available counterexamples compared to other participants. In addition, all typical participants, regardless of processing style, show less influence of available information on invalid inferences, in the complex task compared to the simple condition. In a sense this experiment models what Minshew and colleagues claim happens when individuals with autism are presented with a complex task. The typical adults had to attend to two distinct sets of information whilst experiencing cognitive overload. The results show a reduced effect of background knowledge on invalid inferences suggesting ineffective representations which fail to incorporate all available information. These results mimic those found earlier among the adolescents with ASD in response to the same reasoning questions without a secondary working memory load.

The idea that individuals with autism do not engage in complex integrative processing associated with working memory is closely related to the model of autism proposed by Underconnectivity Theory (Just et al., 2004). A growing number of neuroimaging studies show reduced levels of connectivity across brain regions in autism (e.g. Just et al., 2004; Castelli et al., 2002; Luna et al., 2002), at the same time, anatomical studies also present evidence for unusual development of white matter in the brain, affecting communication between cortical regions (e.g. Courchesne et al., 2001; Herbert et al., 2004). Cortical-cortical connections associated with complex integrative processing show underconnectivity, with more activation in areas associated with simpler processes (Just et al., 2004; Just et al., 2007). There is also evidence for hyperconnectivity in subcortical-cortical connections compensating for reduced

intercortical connectivity (Mizuno et al., 2006). Further evidence for an uneven impairment in connectivity in autism derives from studies of the temporal binding of information (Brock et al., 2002). Communication across brain regions involves two types of integration, temporal binding necessary for complex information processing and combination coding which is sufficient for simple processing. Combination coding is involved, for example, in the representation of object features. Brock et al. (2002) claim that people with autism have a specific difficulty with temporal binding.

Underconnectivity theory shows that poor connectivity, reducing cortical-cortical communication will affect any task requiring high levels of contribution from frontal executive regions. This account, in conjunction with Oberauer and colleague's model of working memory, suggests that the neural circuitry necessary for relational integration to occur may be lacking. Further evidence from neuroimaging studies of autism does indeed demonstrate that individuals with autism employ different areas of the brain when engaged in working memory tasks. For participants with autism working memory is associated with less frontal activation, and increased reliance on posterior brain regions (Koshino et al. 2005; 2008).

It is important to note that reduced connectivity does not always result in poor task performance. Even where neural circuitry is shown to differ, individuals with autism show comparable performance to controls on tasks taken to involve working memory, such as the n-back working memory task (Koshino et al. 2005). The adolescents with ASD included in the studies under discussion did not differ from controls on traditional measures of processing and storage. The experiments reported here also show that individuals with autism are able to use working memory to process and store information, including information about beliefs derived from implicit processes or generated examples of background knowledge. They tend not to go on to integrate such information, however, in the creation of complex models.

Studies exploring connectivity between brain regions during working memory tasks have tended to employ well-used measures such as the n-back task. Such tasks tap processing and

storage components of working memory. Further work is needed, in order to establish whether individuals with autism perform poorly on new tasks designed to measure relational integration in working memory, and whether performance is associated with atypical connectivity between brain regions. This is just one of the many possible areas for future work emerging from this thesis. Ideas for future directions will be discussed in the next section.

Future work

Ideas for new work derive predominantly from major findings of the PhD relating to a tendency not to integrate background knowledge in conditional reasoning. Future work also emerges, however, from typical performance shown by the adolescents with ASD on a number of other tasks. Further ideas address the questions raised by the final two experiments involving possible reasons why contextualisation may not occur in this population.

The fact that adolescents with ASD show a weak or absent influence of context in conditional reasoning extends previous findings associated with information processing accounts of autism by providing evidence from a new domain. There is very little work exploring contextualised reasoning among individuals with autism, a notable exception is the previously discussed study by Pijnacker et al. (2009). Clearly, more work is needed in this area. As previously stated, reasoning in context is primary, adaptive and difficult to suppress in typical populations (see Evans & Over, 2004 for a review). As the belief bias literature shows, when reasoning about the world the responses people give typically reflect background knowledge and beliefs. It is, therefore, likely that individuals with autism will show different patterns of performance compared to controls across a range of tasks involving contextualised reasoning.

Current plans for future work include designing a series of experiments exploring the influence of background knowledge on the selection task (Wason, 1966) among individuals with ASD and typical controls. The work presented in this thesis suggests that individuals with

autism will be less influenced by background information, compared to a typical population, and will consequently not exhibit the customary facilitation afforded by content-rich versions of the task.

The findings of Experiment 2 also highlight the need for further investigation into reasoning among populations with autism. The adolescents with ASD did not show a yes response bias in a simple reasoning task with questions based on a universally quantified major premise. The structure of the questions was taken from the Leever and Harris (2000) study which found evidence for a yes response bias in children with autism. The major difference between our experiment and that of previous studies was the content of the questions. Previous work used material which was contrary-to-fact whereas our experiment used familiar factual content. These mixed findings suggest that reasoning with empirically false material may present particular difficulties for individuals with autism.

The work of Leever and Harris (2000) also highlights the importance of considering developmental factors in reasoning among children and adults with autism. Both the Leever and Harris study and that of Pijnacker et al. (2009) have different age participants to those studied here. With the exception of Experiments 5 and 6, the participants recruited spanned adolescence, a period known to be associated with the development of representational and inhibitory abilities. Further study is necessary in order to examine differences in reasoning performance in the light of such developmental issues. Reasoning ability across wider age ranges needs to be considered, for example, to establish both that patterns of responding do not simply reflect developmental delay, but also the possibility that compensatory mechanisms may impact differently depending on age.

The experiments described in Chapters 3 and 4 pose interesting questions regarding the reasons why individuals with autism may be able to see the bigger picture in some cases but not others. As discussed, the findings show that adolescents with ASD are capable of drawing information together in some cases. They can reason logically where background knowledge is

unavailable. They are also able to make implicit judgments in the light of presented material and can generate counterexamples based on given rules and facts. The final 2 experiments explore possible reasons for this pattern of results based, in part, on the model of working memory proposed by Oberauer and colleagues.

What is of particular interest with regard to new models of working memory is that such models allow for distinctions between levels of integration involving implicit processes, processing and storage of information, and relational integration. Such models provide, therefore, explanatory frameworks for exploring the nature of integration required by different tasks. Such an approach is relevant to investigations of the mixed results associated with global coherence. Of particular urgency is the reconsideration of measures of cognitive capacity to include measures of relational integration. These new measures can help to better assess the ability of individuals with autism to draw together information for meaning on tasks with differing cognitive demands.

Working memory has been implicated in both reasoning on the basis of counterexamples (Verschueren et al., 2004) and also the generation of counterexamples (Verschueren, Schaeken, De Neys, & d'Ydewalle, 2002; De Neys, Schaeken and d'Ydewalle 2005), particularly disabling conditions. These studies raise questions for future work as both the DeNeys et al. (2002) study and the Verschueren et al. studies (2002; 2004) measured working memory capacity using the Ospan (La Point & Engle, 1990). In this task, participants solve a series of simple mathematical problems while holding in mind a list of unrelated words. Despite the fact that Verschueren et al. (2004) suggest that it is relational integration which defines contextualised reasoning the measure used is not specifically designed to tap this aspect of working memory. The tasks taken to measure the relational integration sub-component of working memory are very different (Oberauer et al., 2008), including, for example, the ability to identify the changing relationships between aeroplane and landscape features in a simulated flight control exercise. These measures present exciting possibilities for

exploring the specific aspects of working memory involved in reasoning and other tasks. Particular areas of interest include investigation of the relationship between relational integration measures, traditional processing and storage measures and performance on tasks previously taken to reflect global coherence.

In considering the mixed findings associated with weak central coherence, and the results of this thesis, an important question arises regarding motivation or thinking disposition. Recent conceptions of weak central coherence describe a tendency rather than an inability. This reflects mixed findings generally but also work showing improvement in global processing among individuals with autism where specific instructions are given (e.g. Plaisted et al., 1999).

Stanovich's (2009) model of the mind provides a possible framework for considering the role of disposition on task performance in autism. If thinking disposition involves an unwillingness to contextualize then the reflective mind may not activate the algorithmic mind. As previously described, the algorithmic mind is concerned with complex integrative simulations supporting reasoning or text comprehension. If the algorithmic mind is not activated then an individual will rely on serial associative processing or implicit processing. The question that specifically emerges from Stanovich's work is what role thinking disposition plays in the deployment of resources in complex tasks among individuals with autism. In order to investigate this question it may be necessary to design new dispositional measures which are relevant to this population.

Conclusion

The findings of the PhD present additional evidence for a lack of contextualised processing among adolescents with ASD in a new domain, conditional reasoning. Adolescents with ASD show little influence of background knowledge on two reasoning tasks. In both of these tasks typical participants integrate available information from different sources, including contextual

information, to arrive at a response. It is proposed that a lack of contextualised reasoning stems from a tendency not to combine all available information to create complex integrative or situation models. The creation of such models is effortful and relies on working memory resources. In terms of dual process theory this tendency is associated with System 2. Overburdening working memory reduces the influence of contextual information in typical participants suggesting that working memory plays an active role in the integration of information.

New models of working memory suggest that a central function is the integration of information. A specific domain general sub-component of working memory is responsible for integrating initial bindings and information from different sources. This sub-component is particularly implicated in the creation of complex models in reasoning. Individuals with autism may be unable to make effective use of working memory resources allowing for integration. This may be due to poor connectivity between cortical regions and dispositional factors. A tendency or an inability to integrate information leads to an over reliance on implicit processing, serial associative cognition and piecemeal processing without the support of top down models or schemas. This processing style allows for good performance in many cases. Information can be drawn together through implicit inferences, item to item associations and manipulation of material within a single domain. The results of several tasks presented here, for example, show comparable performance between adolescents with autism and typical controls. Adolescents with autism are able to derive beliefs about the content of statements provided, and they are able to generate information and arrive at meaningful responses on the basis of rules and facts. They are also able to make inferences which rely on the manipulation of presented material. When faced with complex tasks, however, where information from a variety of sources must be drawn together, individuals with autism tend to perform poorly. The application of non-integrative processing in response to complex reasoning tasks is likely

to result in working memory resources being overburdened. The result will be reasoning responses which do not reflect all available contextual information.

References

- Ackerman, P. L., Beier, M. E., Boyle, M. O. (2005). Working memory and intelligence: the same or different constructs? *Psychological Bulletin*, 131, 30-60.
- Ameli, R., Courchesne, E., Lincoln, A., Kaufman, A. S., & Grillon, C. (1988). Visual memory processes in high-functioning individuals with autism. *Journal of Autism and Developmental Disorders*, 18, 601-615.
- American Psychiatric Association (1994) *Diagnostic and Statistical Manual of Mental disorders*, 4th Edition. Washington D.C.: A.P.A.
- Baddeley, A. D. (1986) *Working memory*. Clarendon Press.
- Baddeley, A. (2007). *Working memory, thought, and action*. Oxford, UK: Oxford University Press.
- Baddeley, A. & Hitch, G. J. (1974) Working memory. In: *Recent advances in learning and motivation*, vol. 8, ed. G. Bower. Academic Press.
- Baldo, J. V., Dronkers, N. F., Wilkins, D., Ludy, C., Raskin, P., & Kim, J. Y. (2005). Is problem solving dependent on language? *Brain and Language* 92, 240–250.
- Baron, J. (1988). *Thinking and deciding*. Cambridge, England: Cambridge University Press.
- Baron-Cohen, S. (1989). The autistic child's theory of mind-a case of specific developmental delay. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, 30, 285-297.
- Baron-Cohen, S. (1991). The development of a theory of mind in autism: deviance and delay? *Psychiatric Clinics of North America*, 14, 33-51.
- Baron-Cohen, S. (1993). From attention-goal psychology to belief-desire psychology: The development of a theory of mind and its dysfunction (pp. 59-82). In S. Baron-Cohen, H. Tager-Flusberg, & D.J. Cohen (Eds), *Understanding other minds: Perspective from autism* (pp. 59-82). Oxford: Oxford University Press.
- Baron-Cohen, S. (1995) *Mindblindness: An Essay on Autism and Theory of Mind*. Cambridge, MA: MIT Press.

- Baron-Cohen, S. (2000) Theory of mind and autism: a fifteen year review. In: Baron-Cohen S, Tager-Flusberg H, Cohen D. J, (Eds.), *Understanding other minds: Perspectives from developmental cognitive neuroscience* (pp. 3-20). 2nd ed. Oxford: Oxford University Press.
- 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 and Developmental Disorders*, 31, 5-17
- Baron-Cohen, S. & Hammer, J. (1997). Is autism an extreme form of the male brain? *Advances in Infancy Research*. 11, 193-217.
- 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 and Psychiatry and Allied Disciplines*, 38(7), 813–822.
- Baron-Cohen, S., Leslie, A. M., & Frith, U. (1985). Does the autistic child have a "theory of mind"? *Cognition*, 21, 37-46.
- Bennetto, L., Pennington, B. F., & Rogers, S. J. (1996). Intact and impaired memory functions in autism. *Child Development*, 67, 1816-1835.
- Bishop, D. V. M., & Norbury, C. F. (2005). Executive functions in children with communication impairments in relation to autistic symptomatology 2: Response inhibition. *Autism*, 9, 29-43
- Booth, R. (2006). *Local–global processing and cognitive style in autism spectrum disorder and typical development*. Unpublished PhD thesis, King's College London, London, UK.
- Booth, R., Charlton, R., Hughes, C., & Happe', 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. Series B: Biological Sciences*, 358, 387-392.
- Boucher J. (1981) Immediate free recall in early childhood autism: Another point of behavioral similarity with the amnesic syndrome. *British Journal of Psychology*. 72, 211-215

- Boucher, J. (1988). Word fluency in high-functioning autistic children. *Journal of Autism and Developmental Disorders*, 18, 637-645.
- Bowler, D. M. (1992). Theory of mind in aspergers syndrome. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, 33, 877-893.
- Braine, M. D. S., & O' Brien, D. P. (Eds.). (1998). *Mental Logic*. Mahwah, NJ: Erlbaum.
- Brock, J., Brown, C. C., Boucher, J., & Rippon, G. (2002). The temporal binding deficit hypothesis of autism. *Development and Psychopathology*, 14, 209-224.
- Burack, J. A., Enns, J. T., Iarocci, G., & Randolph, B. (2000). Age differences in visual search for compound patterns: Long- versus short-range grouping. *Developmental Psychology*, 36, 731-740.
- Byrne, R. M. J. (1989). Suppressing valid inferences with conditionals. *Cognition*, 31, 61-83.
- Byrne, R. M. J., Espino, O., & Santamaria, C. (1999). Counterexamples and the suppression of inferences. *Journal of Memory and Language*, 40, 347-373.
- Capon, A., Handley, S. J., & Dennis, I. (2003). Working memory and reasoning: An individual differences perspective. *Thinking & Reasoning*, 9, 203-244.
- Carruthers, P. (1996) *Language thought and consciousness: An essay in philosophical psychology*: New York: Cambridge University Press.
- Carruthers, P. (2002) The cognitive functions of language. *Behavioural and Brain Sciences*, 2, 657-674
- Carruthers, P. (2009a). An architecture for dual reasoning. In J. Evans and K. Frankish (eds.), *In Two Minds: Dual Processes and Beyond*, Oxford University Press.
- Carruthers, P. (2009b). How do we know our own minds: The relationship between mindreading and metacognition. *Behavioral and Brain Sciences*, 32, 121-138.
- Case, R., Kurland, M., & Goldberg, J. (1982). Operational efficiency and the growth of short-term memory span. *Journal of Experimental Child Psychology*, 33, 386-404.
- Castelli F., Frith C., Happe F. & Frith U. (2002) Autism, Asperger syndrome and brain mechanisms for the attribution of mental states to animated shapes. *Brain*, 125, 1839-49

- Cheng, P. W. & Holyoak, K. J. (1985). Pragmatic reasoning schemas. *Cognitive Psychology*, 17, 391-416.
- Chomsky, N. (1995) *The minimalist program*. MIT Press.
- Colom, R., Rebollo, I., Abad, F., & Shih, P.C. (2006). Simple span tasks, complex span tasks and cognitive abilities: A re-analysis of key studies. *Memory & Cognition*, 34, 158-171.
- Colom, R., Rebollo, I., Palacios, A., Juan-Espinosa, M., & Kyllonen, P. C. (2004). Working memory is (almost) perfectly predicted by g. *Intelligence*, 32, 277-296.
- Corballis, M. (2003). Recursion as the key to the human mind. In K. Sterelny & J. Fitness (Eds.), *From mating to mentality: Evaluating evolutionary psychology* (pp. 155-171). New York: Psychology Press.
- Cosmides, L. (1989). The logic of social exchange: has natural selection shaped how humans reason? *Cognition*, 31, 187-276.
- Courchesne, E., Karns, C., Davis, H., Ziccardi, R., Carper, R., Tigue, Z., et al. (2001). Unusual brain growth patterns in early life in patients with autistic disorder: an MRI study. *Neurology* 57, 245-254.
- Cummins, D. D. (1995). Naive theories and causal deduction. *Memory and Cognition*, 23, 646-658.
- Cummins, D. D., Lubart, T., Alksnis, O., & Rist, R. (1991). Conditional reasoning and causation. *Memory & Cognition*, 19, 274-282.
- De Neys, W. (2006). Dual processing in reasoning—Two systems but one reasoner. *Psychological Science*, 17, 428-433
- De Neys, W., Schaeken, W., & d'Ydewalle, G. (2005). Working memory and everyday conditional reasoning: Retrieval and inhibition of stored counterexamples. *Thinking and Reasoning*, 11, 349-381.
- Dias, M. G., & Harris, P. L. (1988). The effect of make-believe play on deductive reasoning. *British Journal of Developmental Psychology*, 6, 207-221.

- Dias, M., & Harris, P.L. (1990). The influence of imagination on reasoning by young children. *British Journal of Developmental Psychology*, 8, 305-318.
- Emerson, M. J., & Miyake, A. (2003). The role of inner speech in task switching: A dual-task investigation. *Journal of Memory and Language*, 48, 148-168.
- Evans, J. St. B. T. (1984) Heuristic and analytic processes in reasoning. *British Journal of Psychology*, 75, 451-468
- Evans, J. St. B. T. (1989) *Bias in Human Reasoning: Causes and Consequences*. Brighton: Erlbaum.
- Evans, J. St. B. T. (1998). Matching bias in conditional reasoning: Do we understand it after 25 years? *Thinking and Reasoning*, 4, 45-82.
- Evans, J. St. B. T. (2002). Logic and Human Reasoning: An Assessment of the Deduction Paradigm. *Psychological Bulletin*, 128, 978-996
- Evans, J. St. B. T. (2003). In two minds: dual process accounts of reasoning. *Trends in Cognitive Sciences*, 7, 454-459.
- Evans, J. St. B. T. (2006a) The heuristic-analytic theory of reasoning: Extension and evaluation. *Psychonomic Bulletin and Review*, 13, 378-395.
- Evans, J. St. B. T. (2006b) Dual system theories of cognition: some issues. *Proceedings of the 28th Annual Meeting of the Cognition Science Society, Vancouver*, 202-207
- Evans, J. St. B. T. (2007). *Hypothetical thinking: Dual process in reasoning and judgment*. Hove, UK: Psychology Press.
- Evans, J. St. B. T. (2008) Dual processing accounts of reasoning, judgment and social cognition. *Annual Review of Psychology*, 5, 255-278.
- Evans, J. St. B. T. (2009). How many dual-process theories do we need? One, two or many? In J. St. B. T. Evans & K. Frankish (Eds) *In Two Minds*. Oxford: Oxford University Press.
- Evans, J. St. B. T., Barston, J. L. & Pollard, P. (1983). On the conflict between logic and belief in syllogistic reasoning. *Memory and Cognition*, 11, 295-306.

- Evans, J. St. B. T. & Brooks, P.G. (1981). Competing with reasoning: A test of the working memory hypothesis. *Current Psychological Research*, 1, 139-147.
- Evans, J. St. B. T., Handley, S. H., & Harper, C. (2001). Necessity, possibility and belief: A study of syllogistic reasoning. *Quarterly Journal of Experimental Psychology*, 54A, 935-958.
- Evans, J. St. B. T., Handley, S. J., & Over, D. E. (2003). Conditionals and conditional probability. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 29, 321-335.
- Evans, J. St. B. T., & Lynch, J. S. (1973). Matching bias in the selection task. *British Journal of Psychology*, 64, 391-397.
- Evans, J. St. B. T. & Over, D. E. (1996). *Rationality and reasoning*. Hove: Psychology Press.
- Evans, J. St. B. T., & Over, D. E. (1997). Two cheers for deductive competence. *Current Psychology of Cognition*, 16, 255-278
- Evans, J. St. B. T., & Over, D. E. (2004). *If*. Oxford: Oxford University Press.
- Fein, D., Dunn, M., Allen, D. A., Aram, D. M., Hall, N., Morris, R., et al. (1996). Neuropsychological and language data. In: Bax, M.C.O., Davies, P.A., Rapin, I., (Eds.) *Clinics in developmental medicine: No. 139. Preschool children with inadequate communication: Developmental language disorder, autism, low IQ*. Press; 1996. (pp. 123-154). London: MacKeith.
- Fiddick, L., Cosmides, L., & Tooby, J. (2000). No interpretation without representation: the role of domain-specific representations and inferences in the Wason selection task. *Cognition*, 77, 1-79.
- Flavell, J. H., Flavell, E. R., & Green, F. L. (1983). Development of the appearance-reality distinction. *Cognitive Psychology*, 15, 95-120.
- Flavell, J. H., Flavell, E. R., & Green, F. L. (1983). Development of the appearance-reality distinction. *Cognitive Psychology*, 15, 95-120.
- Frankish, K. (2004) *Mind and Supermind*, Cambridge University Press.
- Frege, G. (1952). *Translations from the philosophical writings of Gottlob Frege*. (P. Beach & M. Black, Eds.). Oxford, England: Blackwell.

- Frith, U. (1970a). Studies in pattern detection in normal and autistic children: I. Immediate recall of auditory sequences. *Journal of Abnormal Psychology, 76*, 413-420.
- Frith, U. (1970b). Studies in pattern detection in normal and autistic children: II. Reproduction and production of color sequences. *Journal of Experimental Child Psychology, 10*, 120-135.
- Frith, U., (1989). *Autism: explaining the Enigma*. Oxford, UK: Blackwell Publishing.
- Frith, U. (2001) Mind blindness and the brain in autism. *Neuron 32*, 969–979
- Frith, U. (2003). *Autism: Explaining the enigma* (2nd ed.). Oxford, UK: Blackwell Publishing.
- 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.
- Frye D, Zelazo PD, Burack J.A. (1998). Cognitive complexity and control: Implications for theory of mind in typical and atypical development. *Current Directions in Psychological Science 7*, 116-121.
- Frye D, Zelazo PD, Burack J.A. (1998). Cognitive complexity and control: Implications for theory of mind in typical and atypical development. *Current Directions in Psychological Science 7*, 116-121.
- Frye, D., Zelazo, P. D., & Palfai, T. (1995) Theory of Mind and rule-based reasoning. *Cognitive Development, 10*, 483-527.
- Fyffe, C., & Prior, M. (1978). Evidence for language recoding in autistic, retarded, and normal children: A re-examination. *British Journal of Psychology, 69*, 393-402.
- Goel, V. (2007). Anatomy of deductive reasoning. *Trends in Cognitive Sciences, 11*, 435-441.
- Goel, V. and Dolan, R.J. (2003) Explaining modulation of reasoning by belief. *Cognition 87*, B11–B22.
- Grandin, T., (1995) *Thinking in Pictures and other reports from My Life with Autism*. New York, Vintage Books.
- Grant, C. M., Riggs, K. J. & Boucher J. (2004). Counterfactual and Mental State Reasoning in Children with Autism. *Journal of Autism and Developmental Disorders, 34*, 177-188.

- Grant, C.M., Riggs, K.J., & Boucher J. (2004) Counterfactual and Mental State Reasoning in Children with Autism. *Journal of Autism and Developmental Disorders*, 34, 177-188
- Griggs, R. A., & Cox, J. R. (1982). The elusive thematic materials effect in the Wason selection task. *British Journal of Psychology*, 73, 407-420.
- Grinter, E. J., Van Beek, P. L., Maybery, M. T., Badcock, D. R. (2009). Brief Report: Visuospatial Analysis and Self-Rated Autistic-Like Traits. *Journal of Autism and Developmental Disorders*, 39, 670-677.
- Hagoort P. (2005). Broca's complex as the unification space for language. In: Cutler A, editor. *Twenty first century psycholinguistics: four cornerstones*. Mahwah, NJ: Lawrence Erlbaum Associates Publishers. p. 157-172.
- Hagoort, P., & van Berkum, J. (2007). Beyond the sentence given. *Philosophical transactions of The Royal Society, London Series B-Biological Sciences* 362, 801-811.
- Halford, G. S., Cowan, N., & Andrews, G. (2007). Separating cognitive capacity from knowledge: A new hypothesis. *Trends in Cognitive Sciences*, 11, 236-242.
- Halford, G. S., Wilson, W. H., & Phillips, S. (1998). Processing capacity defined by relational complexity: Implications for comparative, developmental, and cognitive psychology. *Behavioral and Brain Sciences*, 21, 803-864.
- Handley, S. J., & Feeney, A. (2007). Representation, pragmatics and process in model-based reasoning. In W. Schaeken, A. Vandierendonck, W. Schroyens, & G. d'Ydewalle (Eds.), *The Mental Models theory of Reasoning: Refinement and Extensions*. Mahwah, NJ: Lawrence Erlbaum.
- Happé, F. G. E. (1994). 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. (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. (1997). Central coherence and theory of mind in autism: Reading homographs in context. *British Journal of Developmental Psychology*, 15, 1-12.
- Happé, F.G.E. and Booth, R.D.L. (2008) The power of the positive: Revisiting weak coherence in autism spectrum disorders. *The Quarterly Journal of Experimental Psychology*, 6, 50-63.
- Happé, F., & Frith, U. (2006) The Weak Coherence Account: Detail-focused Cognitive Style in Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*, 36, 5-25.
- Happé, F., & Loth, E. (2002). 'Theory of mind' and tracking speakers' intentions. *Mind and Language*, 17, 24-36.
- Harris P.L. (1993). Pretending and planning. In *Understanding Other Minds: Perspectives From Autism*, Baron-Cohen S, Tager-Flusberg H, Cohen D.J. (Eds), Oxford University Press, Oxford; 228-246.
- Heavey, L. (2003). Arithmetical savants. In A. J. Baroody, & A. Dowker (Eds.), *The development of arithmetic concepts and skills: Constructing adaptive expertise. Studies in mathematical thinking and learning*, (pp. 409-433). Mahwah, NJ, USA:
- Henle, M. (1962). On the relation between logic and thinking. *Psychological Review*, 69, 366-378.
- Herbert, M. R., Ziegler, D. A., Makris, N., Filipek P. A., Kemper T. L., Normandin J. J., et al. (2004). Localization of white matter volume increase in autism and developmental language disorder. *Annals of Neurology*, 55, 530-40.
- Herbert, M., Ziegler, D., Deutsch, C., O'Brien, L., Lange, N., Bakardjiev, A., et al. (2003). Dissociation of cerebral cortex, subcortical and cerebral white matter volumes in autistic boys. *Brain* 126, 1182-1192.
- Hobson, R. P., Ouston, J., & Lee, T. (1988). What's in a face? The case of autism. *British Journal of Psychology*, 79, 441-453.
- Hughes, C, Russell, J. & Robbins, T. R. (1994). Evidence for executive dysfunction in autism. *Neuropsychologia*, 32, 477-492.

- Hughes, C. & Russell, J. (1993). Autistic children's difficulty with mental disengagement from an object: Its implications for theories of autism. *Developmental Psychology, 16*, 543-549.
- Hui-Chun, H. (2007) *Lexical Context Effects on Speech Perception in Chinese People with Autistic Traits*. Retrieved September 02, 2009 from University of Edinburgh Research Archive: <http://hdl.handle.net/1842/1927>
- Inhelder, B., & Piaget, J. (1958). *The growth of logical thinking*. New York: Basic Books.
- Janveau-Brennan, G., & Markovits, H. (1999). The development of reasoning with causal conditionals. *Developmental Psychology, 35*, 904-911.
- Jarrold, C. (2003). A review of research into pretend play in autism. *Autism, 7*, 379-390.
- Jarrold, C., Boucher, J., & Smith, P.K. (1996) generativity defects in pretend play in autism. *British Journal of Developmental Psychology, 14*, 275-300
- Jarvis, H. L., & Gathercole, S. E. (2003). Verbal and non-verbal working memory and achievements on national curriculum tests at 11 and 14 years of age. *Educational and Child Psychology, 20*, 123-140.
- Johnson-Laird, P. N. (1983). *Mental Models*. Cambridge, England: Cambridge University Press.
- Johnson-Laird, P. N., & Bara, B. G. (1984). Syllogistic inference. *Cognition, 16*, 1-61.
- Johnson-Laird, P. N., & Byrne, R. (1991). *Deduction*. Hove, England: Erlbaum.
- 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 and Psychiatry, 38*, 527-534.
- Jolliffe, T., & Baron-Cohen, S. (1999a). 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. (1999b). The strange stories test: A replication with high-functioning adults with autism or Asperger syndrome. *Journal of Autism and Developmental Disorders, 29*, 395-406.

- Jolliffe, T., & Baron-Cohen, S. (2000) Linguistic processing in high-functioning adults with autism or Asperger syndrome. Can global coherence be achieved? A further test of central coherence theory. *Psychological Medicine*, 30, 1169-1187.
- Jolliffe, T., & Baron-Cohen, S. (1999b). The strange stories test: A replication with high-functioning adults with autism or Asperger syndrome. *Journal of Autism and Developmental Disorders*, 29, 395-406.
- Jolliffe, T., & Baron-Cohen, S. (2000). Linguistic processing in high-functioning adults with autism or Asperger's syndrome. Is global coherence impaired? *Psychological Medicine* 30, 1169-1187.
- Joseph, R. M., McGrath, L. M., Tager-Flusberg, H. (2005). Executive dysfunction and its relation to language ability in verbal school-age children with autism. *Developmental Neuropsychology*, 27, 361-378.
- Jurden, F. H. (1995). Individual differences in working memory and complex cognition. *Journal of Educational Psychology*, 87, 93-102.
- Just, M.A., Cherkassky, V., Keller, T.A., Minshew, N.J. (2004). Cortical activation and synchronization during sentence comprehension in high-functioning autism: evidence of underconnectivity. *Brain* 127, 1811-1821.
- Just, M. A., Cherkassky, V. L., Keller, T. A., Kana, R. K., Minshew N. J. (2007). Functional and anatomical cortical underconnectivity in autism: evidence from an fMRI study of an executive function task and corpus callosum morphometry. *Cerebral Cortex*, 17, 951-961.
- Karmiloff-Smith, A. (1998) Development itself is the key to understanding developmental disorders. *Trends in Cognitive Sciences*, 2, 389-98.
- Klaczynski, P. A. (2000). Motivated scientific reasoning biases, epistemological beliefs, and theory polarization: A two process approach to adolescent cognition. *Child Development*, 71, 1347-1366.

- Klaczynski, P. A. (2000). Motivated scientific reasoning biases, epistemological beliefs, and theory polarization: A two-process approach to adolescent cognition. *Child Development, 71*, 1347-1366.
- Klaczynski, P. A. (2001). Analytic and heuristic processing influences on adolescent reasoning and decision making. *Child Development, 72*, 844-861.
- Klaczynski, P. A., Schuneman, M. J., & Daniel, D. B. (2004). Theories of conditional reasoning: A developmental examination of competing hypotheses. *Developmental Psychology, 40*, 559-571.
- Klauer, K. C., Musch, J., & Naumer, B. (2000). On belief bias in syllogistic reasoning. *Psychological Review, 107*, 852-884.
- Klin, A., Jones, W., Schultz, R., & Volkmar, F. (2003). The enactive mind, or from actions to cognition: lessons from autism. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences, 358*, 345-360.
- Konishi, S., Nakajima, K., Uchida, I., Kikyo, H., Kameyama, M., and Miyashita, Y. (1999). Common inhibitory mechanism in human inferior prefrontal cortex revealed by event-related functional MRI. *Brain, 122*, 981-991.
- Koshino, H., Carpenter, P.A., Minshew, N.J., Cherkassky, D.V.L., Keller, T.A., & Just M.A. (2005) Functional connectivity in an fMRI working memory task in high-functioning autism. *NeuroImage, 24*, 810-821.
- Koshino, H., Carpenter, P.A., Minshew, N.J., Cherkassky, D.V.L., Keller, T.A., & Just M.A. (2008) fMRI Investigation of Working Memory for Faces in Autism: Visual Coding and Underconnectivity with Frontal Areas. *Cerebral Cortex, 18*, 289-300.
- Kray, J., Eber, J., & Lindenberger, U. (2004). Age differences in executive functioning across the lifespan: The role of verbalization in task preparation. *Acta Psychologica, 115*, 143-165.
- Kyllonen, P. C., & Christal, R. E., (1990). Reasoning ability is (little more than) working memory capacity. *Intelligence, 14*, 389-433.

- La Pointe, L. B., & Engle, R. W. (1990). Simple and complex word spans as measures of working memory capacity. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *16*, 1118-1133.
- Langdell, T. (1978). Recognition of faces: An approach to the study of autism. *Journal of Child Psychology & Psychiatry*, *19*, 255-268.
- Leevers, H. J. & Harris, P. L. (2000) Counterfactual Syllogistic Reasoning in Normal 4-Year-Olds, Children with Learning Disabilities, and children with Autism. *Journal of Experimental Child Psychology*, *76*, 64-87.
- Leevers, H. J. & Harris, P. L. (2000) Counterfactual Syllogistic Reasoning in Normal 4-Year-Olds, Children with Learning Disabilities, and children with Autism. *Journal of Experimental Child Psychology*, *76*, 64-87.
- Leevers, H. J. & Harris, P. L. (2000) Counterfactual Syllogistic Reasoning in Normal 4-Year-Olds, Children with Learning Disabilities, and children with Autism. *Journal of Experimental Child Psychology*, *76*, 64-87.
- Leslie, A.M. (1987). Pretense and representation: The origins of "theory of mind". *Psychological Review*, *94*, 412-426.
- Leslie, A.M. (1988). Some implications of pretense for mechanisms underlying the child's theory of mind. In J.W. Astington, P.L. Harris, & D.R. Olson (Eds), *Developing theories of mind* (pp. 19-46). New York: Cambridge University Press
- Leslie, A.M. (1991) *The theory of mind deficit in autism: Evidence for a modular mechanism of development: Natural theory of mind*. Oxford, UK: Blackwell.
- Leslie, A.M., & Roth, D. (1993) What autism teaches us about metarepresentation. In S. Baron-Cohen, H. Tager-flusberg, & D. Cohen (Eds.) *Understanding other minds: Perspectives from autism*. Oxford: Oxford University Press.
- Liu, I., Lo, K., & Wu, J. (1996). A probabilistic interpretation of "if-then". *Quarterly Journal of Experimental Psychology*, *49A*, 828-844.

- Logan, G.D., Schachar, R., & Tannock, R., (1997). Impulsivity and inhibitory control. *Psychological Science* 8, 60–64.
- Lopez, B., & Leekam, S. R. (2003). Do children with autism fail to process information in context? *Journal of Child Psychology & Psychiatry*, 44, 285-300.
- Lord, C. & Paul, R. (1997). Language and communication in autism. In D. J. Cohen & F. R. Volkmar (Eds.), *Handbook of autism and pervasive development disorders, 2nd edition*. New York. John Wiley.
- Luna, B., Minshew, N.J., Garver, K.E., Lazar, N.A., Thulborn, K.R., Eddy, W.F., Sweeney, J.A., (2002). Neocortical system abnormalities in autism: an fMRI study of spatial working memory. *Neurology* 59, 834-840.
- Manktelow, K. I. (1999). *Reasoning and Thinking*. Hove, UK: Psychology Press.
- Mari, M., Castiello, U., Marks, D., Marraffa, C., & Prior, M. (2003). The reach-to-grasp movement in children with autism spectrum disorder. *Philosophical Transactions of The Royal Society Series B*, 358, 393-403.
- Markovits, H. (2000). A mental model analysis of young children's conditional reasoning with meaningful premises. *Thinking & Reasoning*, 6, 335-348.
- Markovits, H., & Barrouillet, P. (2002). The development of conditional reasoning: A mental model account. *Developmental Review*, 22, 5-36.
- Markovits, H., & Barrouillet, P. (2004). Introduction: Why is understanding the development of reasoning important? *Thinking and Reasoning*, 10, 113-121.
- Markovits, H., Fleury, M.-L., Quinn, S., & Venet, M. (1998). The development of conditional reasoning and the structure of semantic memory. *Child Development*, 69, 742-755.
- Markovits, H., & Janveau-Brennan, G. (1999). The development of reasoning with causal conditionals. *Developmental Psychology*, 35, 904-911.
- Markovits, H., & Janveau-Brennan, G. (1999). The development of reasoning with causal conditionals. *Developmental Psychology*, 35, 904-911.

- Markovits, H., & Potvin, F. (2001). Suppression of valid inferences and knowledge structures: The curious effect of producing alternative antecedents on reasoning with causal conditionals. *Memory and Cognition*, *29*, 736-744
- Markovits, H., & Thompson, V. (2008). Different developmental patterns of simple deductive and probabilistic inferential reasoning. *Memory and Cognition*, *36*, 1066-1078.
- Markovits, H., Venet, M., Janveau-Brennan, G., Malfait, N., Pion, N., & Vadeboncoeur, I. (1996). Reasoning in young children: Fantasy and information retrieval. *Child Development*, *67*, 2857-2872.
- Markovits, H., Venet, M., Janveau-Brennan, G., Malfait, N., Pion, N., & Vadeboncoeur, I. (1996). Reasoning in young children: Fantasy and information retrieval. *Child Development*, *67*, 2857-2872.
- Matson, J. L. & Wilkins, J. (2008). Nosology and diagnosis of Asperger's syndrome. *Research in Autism Spectrum Disorders*, *2*, 288-300
- Matson, J. L., & Boisjoli, J. A. (2008) Strategies for assessing Asperger's syndrome: A critical review of data based methods. *Research in Autism Spectrum Disorders*, *2*, 237-248
- Maybery, M., Whitehouse, A., Durkin, K. & Comerford, B. (2007). *Limited use of inner speech in autism*. Manuscript submitted for peer review to the Biennial Australian Conference on Autism Spectrum Disorders.
- Minshew N. J., Goldstein G. (2001). The pattern of intact and impaired memory functions in autism. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *42*, 1095-1101.
- Minshew, N. J., Goldstein, G., & Seigel, D. J. (1995). Speech and language in high-functioning autistic individuals. *Neuropsychology*, *9*, 255-261.
- Minshew, N. J., Goldstein, G., Muenz, L. R., & Payton, J. (1992). Neuropsychological functioning in nonmentally retarded autistic individuals. *Journal of Clinical and Experimental Neuropsychology*, *14*, 749-761.

- Minshew, N.J., Goldstein, G., Siegel, D.J., (1997). Neuropsychologic functioning in autism: profile of a complex information processing disorder. *Journal of the International Neuropsychological Society, 3*, 303-316.
- 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., Meyer J., Goldstein G. (2002). Abstract reasoning in autism: a dissociation between concept formation and concept identification. *Neuropsychology, 16*, 327-334.
- Mithen, S. 1996: *The Prehistory of the Mind*. London: Thames and Hudson.
- Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., & Howeter, A. (2000). The Unity and Diversity of Executive Functions and Their Contributions to Complex “Frontal Lobe” Tasks: A Latent Variable Analysis. *Cognitive Psychology, 41*, 49-100
- Mizuno A, Villalobos M. E., Davies M. M., Dahl B. C., Müller R. A., (2006) Partially enhanced thalamo-cortical functional connectivity in autism. *Brain Research, 1104*, 160-174.
- Morgan, B., Maybery, M., & Durkin, K. (2003). Weak central coherence, poor joint attention, and low verbal ability: Independent deficits in early autism. *Developmental Psychology, 39*, 646-656.
- Morley, N. J., Evans, J. St. B. T., & Handley, S. J. (2004). Belief bias and figural bias in syllogistic reasoning. *Quarterly Journal of Experimental Psychology Section A: Human Experimental Psychology, 57*, 666-692.
- Morsanyi, K., & Handley, S. J. (2008). How smart do you need to be to get it wrong? The Role of cognitive capacity in the development of heuristic-based judgment. *Journal of Experimental Child Psychology, 99*, 18-36.
- Mottron, L., & Burack, J. A. (2001). Enhanced perceptual functioning in the development of autism. In P. R. Zelazo (Ed.), *The development of autism: Perspectives from theory and research* (pp. 131-148). Mahwah, NJ: Lawrence Erlbaum Associates.

- Mottron, L., Burack, J. A., Iarocci, G., Belleville, S., & Enns, J. T. (2003). Locally oriented perception with intact global processing among adolescents with high-functioning autism: Evidence from multiple paradigms. *Journal of Child Psychology and Psychiatry*, *44*, 904-913.
- Muller, R.A., Behen, M.E., Rothermel, R.D., Chugani, D.C., Muzik, O., Mangner, T.J., Chugani, H.T., (1999). Brain mapping of language and auditory perception in high-functioning autistic adults: a PET study. *Journal of Autism and Developmental Disorders*. *29*, 19-31.
- Muller, U., Overton, W. F., & Reese, K. (2001). Development of conditional reasoning: A longitudinal study. *Journal of Cognition and Development*, *2*, 27-49.
- Murray, D., Lesser, M., Lawson, W. (2005) Attention, monotropism and the diagnostic criteria for autism. *Autism*, *9*, 139-156.
- Nelson, T., Biernat, M., & Manis, M.(1990). Everyday Base rates (sex stereotypes): Potent and resilient. *Journal of Personality and Social Psychology*, *59*, 664-675.
- Newstead, S. E., Pollard, P., Evans, J. St. B. T., & Allen, J. L. (1992). The source of belief bias effects in syllogistic reasoning. *Cognition*, *45*, 257-284.
- Nielsen, M., & Dissanayake, C. (2001). A study of pretend play and false belief in pre-school children: is all pretence metarepresentational? In S. Reifel (Ed.), *Play and culture studies* (pp. 199-216). London: JAI Press.
- novel, highly similar stimuli by adults with autism during a perceptual learning task. *The Journal of Child Psychology and Psychiatry*, *39*, 765-775.
- 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.
- Oaksford, M., & Chater, N. (1995). Theories of reasoning and the computational explanation of everyday inference. *Thinking and Reasoning*, *1*, 121-152.
- Oaksford, M., & Chater, N. (1998). *Rationality in an uncertain world*. Hove: Psychology Press.
- Oaksford, M., & Chater, N. (2001). The probabilistic approach to human reasoning. *Trends in Cognitive Sciences*, *5*, 349-357.

- Oaksford, M. & Chater, N. (2007). *Bayesian Rationality: The Probabilistic Approach to Human Reasoning*. Oxford University Press. Oxford.
- Oaksford, M., Chater, N., & Larkin, J. (2000). Probabilities and polarity biases in conditional inference. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 26, 883–899.
- Oberauer, K., Süß, H. M., Wilhelm, O., & Wittmann, W. W. (2003). The multiple faces of working memory-storage, processing, supervision, and coordination. *Intelligence*, 31, 167-193.
- Oberauer, K., Süß, H. M., Wilhelm, O., & Sander, N. (2007). Individual differences in working memory capacity and reasoning ability. In A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake, & J. N. Towse (Eds.), *Variation in working memory*. New York: Oxford University Press.
- Oberauer, K., Süß, H. M., Wilhelm, O., & Wittman, W. W., (2008). Which working memory functions predict intelligence? *Intelligence*, 36, 641-652.
- Ozonoff, S., & Jensen, J. (1999). Brief report: Specific executive function profiles in three neurodevelopmental disorders. *Journal of Autism and Developmental Disorders*, 29, 171-177.
- Ozonoff, S., & McEvoy, R. E. (1994). A longitudinal study of executive function and theory of mind development in autism. *Development and Psychopathology*, 6, 415-431.
- 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.L., 2001. Further evidence of intact working memory in autism. *J. Autism Dev. Disord.* 31, 257-263.
- Ozonoff, S., Strayer, D.L., McMahon, W.M., & Filloux, F. (1994). Executive function abilities in autism and Tourette's syndrome: An information processing approach. *Journal of Child Psychology and Psychiatry*, 35, 1015–1032.
- Papafragou, A. (2002). Mindreading and verbal communication. *Mind and Language*, 17 55-67.
- Perner, J. (1991) *Understanding the representational mind*. Cambridge, MA: Bradford.
- Perner, J. (1991). *The representational theory of mind*. Cambridge, MA: MIT Press.

- Peterson D.M., Bowler D.M. (2000). Counterfactual reasoning and false belief understanding in children with autism, children with severe learning difficulties, and children with typical development, *Autism*, 4, 391-405.
- Peterson, D. & Riggs, K. J. (1999) Adaptive modelling and mindreading. *Mind and Language*, 14, 80-112.
- Pijnacker, J., Geurts, B., van Lambalgen, M., Kan, C. C., Buitelaar, J. K., & Hagoort, P. (2009). Defeasible reasoning in high-functioning adults with autism: Evidence for impaired exception-handling. *Neuropsychologia*, 47, 644-651.
- 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: Perspectives from theory and research*. (pp.149-169). New Jersey: Lawrence Erlbaum.
- Plaisted, K.C., O'Riordan, M., Baron-Cohen, S. (1998a). Enhanced discrimination of novel, highly similar stimuli by adults with autism during a perceptual learning task. *The Journal of Child Psychology and Psychiatry*, 39, 765-775.
- Plaisted, K.C., O'Riordan, M., Baron-Cohen, S., (1998b). Enhanced visual search for a conjunctive target in autism: a research note. *Journal of Child Psychology and Psychiatry* 39, 777-783.
- Plaisted, K.C., 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.
- Pollard, P. (1982). Human reasoning: some possible effects of availability. *Cognition*, 12, 65-96.
- Pollard, P. & Evans, J. St. B. T. (1987). On the relationship between content and context effects in reasoning. *American Journal of Psychology*, 100, 41-60.
- Porporino, M., Shore, D. I., Iarocci, G., & Burack, J. A. (2004). A developmental change in selective attention and global form perception. *International Journal of Behavioral Development*, 28, 358-364.

- Prabhakaran, V., Narayanan, K., Zhao, Z., Gabrieli, J.D., (2000). Integration of diverse information in working memory within the frontal lobe. *Nature Neuroscience* 3, 85-90.
- Premack, D. and Woodruff, G. (1978) Does the chimpanzee have a 'theory of mind'? *Behavioral & Brain Sciences*. 4, 515-526.
- 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.
- Quinn, S., & Markovits, H. (1998). Conditional reasoning, causality, and the structure of semantic memory: Strength of association as a predictive factor for content effects. *Cognition*, 68, B93-101.
- Reyna, V. F., & Kiernan, B. (1994). Development of gist versus verbatim memory in sentence recognition: Effects of lexical familiarity, semantic content, encoding instructions, and retention interval. *Developmental Psychology*, 30, 178-191.
- Riggs, K. J. & Peterson, D. M. (2000). Counterfactual Thinking in pre-school children: mental state and causal inference. In P. Mitchell & K. J. Riggs (Eds) *Children's Reasoning and the Mind*. Hove: Psychology Press.
- Rips, L. J. (1994). *The psychology of proof*. Cambridge, MA: MIT Press.
- 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.
- Russell, J., Jarrold, C., & Hood, B. (1999). Two intact executive capacities in children with autism: Implications for the core executive dysfunctions in the disorder. *Journal of Autism and Developmental Disorders*, 29, 103-112.
- Russell, J., Jarrold, C., & Henry, L. (1996). Working memory in children with autism and with moderate learning difficulties. *Journal of Child Psychology and Psychiatry*, 37, 673-686.
- Saldana, D., Frith, U. (2007) Do readers with autism make bridging inferences from world knowledge? *Journal of Experimental Child Psychology*, 96, 310-319

- Scott, F. J., Baron-Cohen, S. & Leslie, A. (1999) 'If pigs could fly': A test of counterfactual reasoning and pretence in children with autism. *British Journal of Developmental Psychology*, 17, 349-362.
- Scott, S. (2001). *Metarepresentation in philosophy and psychology*. In proceedings of the 23rd annual Conference of The Cognitive Science Society. Lawrence Erlbaum Associates.
- Shah, A., & Frith, U. (1993). Why do autistic individuals show superior performance on the Block Design task? *Journal of Child Psychology and Psychiatry*, 34, 1351-1364.
- 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, P., & Miyake, A. (1996). The separability of working memory resources for spatial thinking and language processing: An individual differences approach. *Journal of Experimental Psychology: General*, 125, 4-27.
- Singer, M., & Halldorson, M. (1996). Constructing and validating motive bridging inferences. *Cognitive Psychology*, 30, 1-38.
- Sloman, S. A. (1996). The empirical case for two systems of reasoning. *Psychological Bulletin*, 119, 3-22.
- Sloman, S. A. (2002). Two systems of reasoning. In T. Gilovich, D. Griffin, & D. Kahneman (Eds.), *Heuristics and biases: The psychology of intuitive judgment* (pp. 379-398). Cambridge, UK: Cambridge University Press.
- Smedslund, J. (1970). Circular relation between understanding and logic. *Scandinavian Journal of Psychology*, 11, 217-219.
- Snowling, M. & Frith, U. (1986). Comprehension in 'Hyperlexic' Readers. *Journal of Experimental Child Psychology*, 42, 392-415.
- 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*, 11, 2765-2767.

- Sperber, D. Ed. (2000) *Metarepresentations a multidisciplinary perspective*. Oxford: Oxford University Press.
- Sperber, D., Cara, F. & Girotto, V. (1995). Relevance theory explains the selection task. *Cognition*, 57, 31-95.
- Stanovich, K. E. (1999). *Who is Rational? Studies of Individual Differences in Reasoning*. Mahway, NJ: Erlbaum.
- Stanovich, K. E. (2004). *The Robot's Rebellion: Finding Meaning the age of Darwin*. Chicago: Chicago University Press.
- Stanovich, K. E. (2009). Distinguishing the reflective, algorithmic, and autonomous minds: Is it time for tri-process theory? In J. St. B. T. Evans & K. Frankish (Eds) *In Two Minds*. Oxford: Oxford University Press.
- Stanovich, K. E. & West, R.F. (1997). Reasoning independently of prior belief and individual differences in actively open-minded thinking. *Journal of Educational Psychology*, 89, 342-357.
- Stanovich, K. E. & West, R.F. (1998a) Individual differences in rational thought. *Journal of Experimental Psychology: General*, 127, 161-179.
- Stanovich, K. E. & West, R.F. (1998b) Who uses base rates and P(D/~H)? An analysis of individual differences. *Memory & Cognition*, 28, 161-179.
- Stanovich, K. E. & West, R.F. (1998c) Cognitive ability and variation in selection task performance. *Thinking & Reasoning*, 4, 193-230.
- Stewart, M. E., Watson, J., Allcock A. J., & Yaqoob, T. A. (2009). Autistic traits predict performance on the block design. *Autism*, 13, 133-142.
- Stone, V. E., & Gerrans, P. (2006). Does the normal brain have a theory of mind? Thoughts on modularity in response to Apperly et al. *Trends in Cognitive Sciences*, 10, 3-4.
- 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.

- Tager-Flusberg, H. (1996). Current theory and research on language and communication in autism. *Journal of Autism and Developmental Disorders*, 26, 169-172.
- Tager-Flusberg, H. (2000). Language and understanding minds: Connections in autism. In S. Baron-Cohen, H. Tager-Flusberg, & D. Cohen (Eds.), *Understanding other minds: Perspectives from developmental cognitive neuroscience* (pp. 124-149). New York: Oxford University Press.
- Teunisse, J. P., & de Gelder, B. (2003). Face processing in adolescents with autistic disorder: The inversion and composite effects. *Brain & Cognition*, 52, 285-294.
- Teunisse, J.-P., Cools, A. R., van Spaendonck, K. P. M., Aerts, F. H., & Berger, H. J. (2001). Cognitive styles in high-functioning adolescents with autistic disorder. *Journal of Autism and Developmental Disorders*, 31, 55-66.
- Thompson, V. A. (1994). Interpretational factors in conditional reasoning. *Memory & Cognition*, 22, 742-758.
- Toms, M., Morris, N. & Ward, D. (1993) Working memory and conditional reasoning. *Quarterly Journal of Experimental Psychology*, 46, 679-99.
- Toplak, M., & Stanovich, K. E. (2002). The domain specificity and generality of disjunctive reasoning: Searching for a generalizable critical thinking skill. *Journal of Educational Psychology*, 94, 197-209.
- Toplak, M. E., & Stanovich, K. E. (2003). Associations between myside bias on an informal reasoning task and amount of post-secondary education. *Applied Cognitive Psychology*, 17, 851-860.
- 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.
- Tymchuck, A. J., Simmons, J. Q., Neafsey, S. (1977) Intellectual characteristics of adolescent childhood psychotics with high verbal ability. *Journal of mental Deficiency Research*, 21, 133-138.

- Verschueren, N., De Neys, W., Schaeken, W., & d'Ydewalle, G. (2002). Working memory capacity and the nature of generated counterexamples. *Proceedings of the Annual Conference of the Cognitive Science Society*, 24, 914-999.
- Verschueren, N., Schaeken, W., & d'Ydewalle, G. (2004). Everyday conditional reasoning with working memory preload. In *Proceedings of the Twenty-Sixth Annual Meeting of the Cognitive Science Society* (pp. 1399-1404). Mahwah, NJ: Erlbaum.
- Verschueren, N., Schaeken, W., & d'Ydewalle, G. (2005a). A dual-process specification of causal conditional reasoning. *Thinking and Reasoning*, 11, 239-278.
- Verschueren, N., Schaeken, W., & d'Ydewalle, G. (2005b). Everyday conditional reasoning: A working memory-dependent tradeoff between counterexample and likelihood use. *Memory and Cognition*, 33, 107-119.
- Vygotsky, L. S. (1981). The genesis of higher mental functions. In J. V. Wertsch (Ed.), *The concept of activity in Soviet psychology* (pp. 148-188). Armonk, NY: Sharpe.
- 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.
- Wason, P. C. (1960). On the failure to eliminate hypotheses in a conceptual task. *Quarterly Journal of Experimental Psychology*, 12, 129-140
- Wason, P. C. (1966). Reasoning. In B. M. Foss (Ed.), *New horizons in psychology: 1* (pp.106-137). Harmandsworth, England: Penguin.
- Wason, P. C. & Evans, J. St. B. T. (1975). Dual processes in reasoning? *Cognition*, 3, 141-154.
- Wason, P. C. & Shapiro, D. (1971). Natural and contrived experience in a reasoning problem. *Quarterly Journal of Experimental Psychology*, 23, 63-71.
- Wechsler, D. (1991). *Wechsler Intelligence Scale for Children* (3rd ed.). New York: Psychological Corporation.

- Weidenfield, A., Oberauer, K., & Hornig, R. (2005). Causal and noncausal conditionals: An integrated model of interpretation and reasoning. *The Quarterly Journal of Experimental Psychology* 58A, 1479-1513.
- Wheeler, M. E., & Treisman, A. M. (2002). Binding in short-term visual memory. *Journal of Experimental Psychology: General*, 131, 48-64.
- Whitehouse, A. J. O., Maybery, M. T., Durkin, K. (2006) Inner speech impairments in autism. *Journal of Child Psychology and Psychiatry*, 47, 857-865.
- Whiten, A. (1996) Imitation, pretence and mind reading: secondary representation in comparative primatology and developmental psychology? In A. E. Russon, K. A. Bard & S. T. Parker (Eds.), *Reaching into thought: The minds of the great apes*. Cambridge: Cambridge University Press.
- Wilkinson, K. (1998). Profiles of language and communication skills in autism. *Mental Retardation and Developmental Disabilities Research Reviews*, 4 73-79.
- Williams, D. L., Goldstein, G., Minshew, N. J. (2005). Impaired memory for faces and social scenes in autism: clinical implications of memory dysfunction. *Archives of Clinical Neuropsychology*, 20, 1-15.
- Williams, D. L., Goldstein, G. & Minshew, N. J. (2006a). Neuropsychologic functioning in children with autism: Further evidence for disordered complex information-processing. *Child Neuropsychology*, 12, 279-298.
- Williams, D. L., Goldstein, G. & Minshew, N. J. (2006b). The profile of memory function in children with autism. *Neuropsychology* 20, 21-29.
- Wilson, M. Bettger, J. G. Niculae, I and. Klima, E.S. (1997) Modality of Language Shapes Working Memory: Evidence from Digit Span and Spatial Span in ASL Signers. *Journal of Deaf Studies. Deaf Education*, 2, 150-160.
- Woodbury-Smith, M.R., Robinson, J., Wheelwright, S., Baron-Cohen, S., (2005). Screening adults for Asperger Syndrome using the AQ: a preliminary study of its diagnostic validity in clinical practice. *Journal of Autism and Developmental Disorders*. 35, 331-335.

World Health Organization. (1993). *International classification of diseases* (10th ed.). Geneva, Switzerland.

Zelazo PD, Frye D. 1997. Cognitive complexity and control: A theory of the development of deliberate reasoning and intentional action. In *Language Structure, Discourse, and the Access to Consciousness*, Stamenov M. (ed). John Benjamins: Amsterdam; 113–153.

Zelazo PD, Frye D. 1998. II. Cognitive complexity and control: the development of executive function. *Current Directions in Psychological Science*, 7, 121–126.

Zelazo, P.D., Jaques, S., Burack J, A., & Frye D. (2002) The Relation between Theory of Mind and Rule Use: Evidence from Persons with Autism-Spectrum Disorders. *Infant and Child Development*, 11, 171-195.

Zwaan, R.A., Radvansky, G. A. (1998) Situation Models in Language Comprehension and Memory. *Psychological Bulletin*, 123, 162-185.

Appendix A1

Conditionals used in the reasoning task in Experiment 1:

Low alternatives and low disablers

If butter is heated, then it will melt

If iron touches a magnet, then it will stick to it

If water is frozen, then it will become ice

If Robert cuts his finger, then it will bleed

High alternatives and high disablers

If the brake is pressed, then the car will slow down

If the window is opened, then the room will become cool

If a stone is kicked, then it will move

If a mug is dropped, then it will break

High disablers and low alternatives

If the ignition key is turned, then the car will start

If the trigger is pulled, then the gun will fire

If the correct switch is flicked, then the porch light will go on

If the doorbell is pushed, then it will ring

High alternatives and low disablers

If the apple is ripe, then it will fall off the tree

If Camilla eats an ice-lolly, then her mouth will get cold

If a towel is dropped in the bath, then it will get wet

If a balloon is pricked, then it will burst

Appendix A2

Questions used in Experiment 2:

MP standard	All birds have feathers	All fish can swim
	Robins are birds	Sharks are fish
	Does it follow that robins have feathers?	Does it follow that sharks can swim?

MP opposite	All fires are hot	All big cats are fast
	A bonfire is a fire	A cheetah is a big cat
	Does it follow that a bonfire is cold?	Does it follow that cheetahs are slow

MT standard	All insects need oxygen	All animals need food
	Stones don't need oxygen	Rugs don't need food
	Does it follow that stones are insects?	Does it follow that rugs are animals?

MT opposite	All hot things can burn you	All old people have wrinkles
	An ice cube can't burn you	Teenagers don't have wrinkles
	Does it follow that an ice cube is cold?	Does it follow that teenagers are young?

AC standard	All flowers have petals	All birds lay eggs
	Roses have petals	Eagles lay eggs
	Does it follow that roses are flowers?	Does it follow that eagles are birds?
AC opposite	All tall animals can eat high up leaves	All small objects can fit inside a cup
	Giraffes can eat high up leaves	A pin can fit inside a cup
	Does it follow that Giraffes are short?	Does it follow that a pin is big?
DA standard	All reptiles have scales	All dogs bark
	Bears are not reptiles	Rabbits are not dogs
	Does it follow that bears have scales?	Does it follow that rabbits bark?
DA opposite	All lemons are sour	All fires are hot
	Chocolates are not lemons	A snowball is not a fire
	Does it follow that chocolates are sweet?	Does it follow that a snowball is cold?

Appendix A3

Questions used in the generation task in Experiment 3. High/low availability of counterexamples and type of inference is added in parentheses.

Practice question

Rule: If Marvin wears wellies, then his feet will stay dry.

Fact: Marvin's feet stay dry, but he is not wearing wellies.

Tell the experimenter as many reasons as you can that could make this possible.

(MP High disablers/low alternatives)

Rule: If the ignition key is turned, then the car will start

Fact: The ignition key was turned, but the car did not start.

Tell the experimenter as many reasons as you can that could make this possible.

(AC High alternatives/ high disablers)

Rule: If the window is opened, then the room will become cool.

Fact: The room becomes cool, but the window was not opened.

Tell the experimenter as many reasons as you can that could make this possible.

(AC High alternatives/low disablers)

Rule: If a towel is dropped in the bath, then it will get wet.

Fact: A towel gets wet, but it is not dropped in the bath.

Tell the experimenter as many reasons as you can that could make this possible.

(MP Low alternatives/low disablers)

Rule: If butter is heated, then it will melt.

Fact: Butter is heated, but it does not melt.

Tell the experimenter as many reasons as you can that could make this possible.

(MP high alternatives/ high disablers)

Rule: If the window is opened, then the room will become cool.

Fact: The window is opened, but the room does not become cool.

Tell the experimenter as many reasons as you can that could make this possible.

(AC high disablers/low alternatives)

Rule: If the ignition key is turned, then the car will start.

Fact: The car started, but the ignition key was not turned

Tell the experimenter as many reasons as you can that could make this possible.

(MP high alternatives/low disablers)

Rule: If a towel is dropped in the bath, then it will get wet.

Fact: A towel is dropped in the bath, but it does not get wet.

Tell the experimenter as many reasons as you can that could make this possible.

(AC Low alternatives/low disablers)

Rule: If butter is heated, then it will melt.

Fact: Butter melts, but it was not heated.

Tell the experimenter as many reasons as you can that could make this possible.

Appendix A4

Conditionals used in the suppression task in Experiment 4:

Simple statements	Additional arguments
If Mary goes shopping, then she buys some fruit.	If the grocer is open, then Mary buys some fruit.
If Chet meets his brother, then he goes ice skating.	If Chet has a warm coat on, then he goes ice skating.
If Amina has homework, then she will work in the sitting room.	If the sitting room is quiet, then Amina will work in the sitting room.
If it is windy, then Gemma's hair gets messed up.	If Gemma goes out, then her hair gets messed up.
If Liam has a long lunch break, then he rings his girlfriend.	If Liam's mobile phone is charged, then he rings his girlfriend
If Laura goes out with her friend, then she will go to her favourite restaurant.	If Laura has enough money, then she will go to her favourite restaurant.
If John goes to the caravan, then he will play scrabble.	If John packs his favourite games, then he will play scrabble.
If Tam has a babysitter, then she will go to the exercise class.	If the babysitter is on time, then she will go to the exercise class.

Simple statements	Alternative arguments
If Paul goes fishing, then he has a fish supper	If Paul goes to the fishmarket, then he has a fish supper
If Susan meets her friend, then she goes to the cinema.	If Susan meets her family, then she goes to the cinema.
If Rosa has a report to write, then she studies in the library all evening.	If Rosa has some textbooks to read, then she studies in the library all evening.
If it rains, then Alex gets wet.	If it snows, then Alex gets wet.
If Luke takes the afternoon off work, then he mows the lawn.	If it is the weekend, then Luke mows the lawn.
If Laura cooks dinner, then she has a nice meal.	If Laura buys a takeaway, then she has a nice meal.
If Jack goes to the beach, then he will fly a kite.	If Jack goes to the playing field, then he will fly a kite.
If Mei goes to the beach, then she will go swimming.	If Mei goes to the swimming pool, then she will go swimming.

Appendix A5

Autism Quotient Questionnaire (AQ)

Name:..... Sex:.....

Date of birth:..... Today's Date:.....

How to fill out the questionnaire

Below are a list of statements. Please read each statement very carefully and rate how strongly you agree or disagree with it by circling your answer.

DO NOT MISS ANY STATEMENT OUT.

Examples

E1. I am willing to take risks.	definitely agree	slightly agree	slightly disagree	definitely disagree
E2. I like playing board games.	definitely agree	slightly agree	slightly disagree	definitely disagree
E3. I find learning to play musical instruments easy.	definitely agree	slightly agree	slightly disagree	definitely disagree
E4. I am fascinated by other cultures.	definitely agree	slightly agree	slightly disagree	definitely disagree

1. I prefer to do things with others rather than on my own.	definitely agree	slightly agree	slightly disagree	definitely disagree
2. I prefer to do things the same way over and over again.	definitely agree	slightly agree	slightly disagree	definitely disagree
3. If I try to imagine something, I find it very easy to create a picture in my mind.	definitely agree	slightly agree	slightly disagree	definitely disagree
4. I frequently get so strongly absorbed in one thing that I lose sight of other things.	definitely agree	slightly agree	slightly disagree	definitely disagree
5. I often notice small sounds when others do not.	definitely agree	slightly agree	slightly disagree	definitely disagree
6. I usually notice car number plates or similar strings of information.	definitely agree	slightly agree	slightly disagree	definitely disagree
7. Other people frequently tell me that what I've said is impolite, even though I think it is polite.	definitely agree	slightly agree	slightly disagree	definitely disagree
8. When I'm reading a story, I can easily imagine what the characters might look like.	definitely agree	slightly agree	slightly disagree	definitely disagree
9. I am fascinated by dates.	definitely agree	slightly agree	slightly disagree	definitely disagree
10. In a social group, I can easily keep track of several different people's conversations.	definitely agree	slightly agree	slightly disagree	definitely disagree
11. I find social situations easy.	definitely agree	slightly agree	slightly disagree	definitely disagree
12. I tend to notice details that others do not.	definitely agree	slightly agree	slightly disagree	definitely disagree
13. I would rather go to a library than a party.	definitely agree	slightly agree	slightly disagree	definitely disagree
14. I find making up stories easy.	definitely agree	slightly agree	slightly disagree	definitely disagree
15. I find myself drawn more strongly to people than to things.	definitely agree	slightly agree	slightly disagree	definitely disagree
16. I tend to have very strong interests which I get upset about if I can't pursue.	definitely agree	slightly agree	slightly disagree	definitely disagree
17. I enjoy social chit-chat.	definitely agree	slightly agree	slightly disagree	definitely disagree
18. When I talk, it isn't always easy for others to get a word in edgeways.	definitely agree	slightly agree	slightly disagree	definitely disagree
19. I am fascinated by numbers.	definitely agree	slightly agree	slightly disagree	definitely disagree

20. When I'm reading a story, I find it difficult to work out the characters' intentions.	definitely agree	slightly agree	slightly disagree	definitely disagree
21. I don't particularly enjoy reading fiction.	definitely agree	slightly agree	slightly disagree	definitely disagree
22. I find it hard to make new friends.	definitely agree	slightly agree	slightly disagree	definitely disagree
23. I notice patterns in things all the time.	definitely agree	slightly agree	slightly disagree	definitely disagree
24. I would rather go to the theatre than a museum.	definitely agree	slightly agree	slightly disagree	definitely disagree
25. It does not upset me if my daily routine is disturbed.	definitely agree	slightly agree	slightly disagree	definitely disagree
26. I frequently find that I don't know how to keep a conversation going.	definitely agree	slightly agree	slightly disagree	definitely disagree
27. I find it easy to "read between the lines" when someone is talking to me.	definitely agree	slightly agree	slightly disagree	definitely disagree
28. I usually concentrate more on the whole picture, rather than the small details.	definitely agree	slightly agree	slightly disagree	definitely disagree
29. I am not very good at remembering phone numbers.	definitely agree	slightly agree	slightly disagree	definitely disagree
30. I don't usually notice small changes in a situation, or a person's appearance.	definitely agree	slightly agree	slightly disagree	definitely disagree
31. I know how to tell if someone listening to me is getting bored.	definitely agree	slightly agree	slightly disagree	definitely disagree
32. I find it easy to do more than one thing at once.	definitely agree	slightly agree	slightly disagree	definitely disagree
33. When I talk on the phone, I'm not sure when it's my turn to speak.	definitely agree	slightly agree	slightly disagree	definitely disagree
34. I enjoy doing things spontaneously.	definitely agree	slightly agree	slightly disagree	definitely disagree
35. I am often the last to understand the point of a joke.	definitely agree	slightly agree	slightly disagree	definitely disagree
36. I find it easy to work out what someone is thinking or feeling just by looking at their face.	definitely agree	slightly agree	slightly disagree	definitely disagree
37. If there is an interruption, I can switch back to what I was doing very quickly.	definitely agree	slightly agree	slightly disagree	definitely disagree
38. I am good at social chit-chat.	definitely agree	slightly agree	slightly disagree	definitely disagree
39. People often tell me that I keep going on and on about the same thing.	definitely agree	slightly agree	slightly disagree	definitely disagree

40. When I was young, I used to enjoy playing games involving pretending with other children.	definitely agree	slightly agree	slightly disagree	definitely disagree
41. I like to collect information about categories of things (e.g. types of car, types of bird, types of train, types of plant, etc.).	definitely agree	slightly agree	slightly disagree	definitely disagree
42. I find it difficult to imagine what it would be like to be someone else.	definitely agree	slightly agree	slightly disagree	definitely disagree
43. I like to plan any activities I participate in carefully.	definitely agree	slightly agree	slightly disagree	definitely disagree
44. I enjoy social occasions.	definitely agree	slightly agree	slightly disagree	definitely disagree
45. I find it difficult to work out people's intentions.	definitely agree	slightly agree	slightly disagree	definitely disagree
46. New situations make me anxious.	definitely agree	slightly agree	slightly disagree	definitely disagree
47. I enjoy meeting new people.	definitely agree	slightly agree	slightly disagree	definitely disagree
48. I am a good diplomat.	definitely agree	slightly agree	slightly disagree	definitely disagree
49. I am not very good at remembering people's date of birth.	definitely agree	slightly agree	slightly disagree	definitely disagree
50. I find it very easy to play games with children that involve pretending.	definitely agree	slightly agree	slightly disagree	definitely disagree

Appendix B1 Experiment 1

Table 1.1 ANOVA performed on MP data from the conditional reasoning task in Experiment

1. 2x group 2x availability of disablers

	SS	df	MS	F	p	η^2_p
Intercept	5164.388	1	5164.388	964.199	.000	.940
DISABLERS	6.751	1	6.751	5.816	.019	.086
DISABLERS* GROUP	7.907	1	7.907	6.812	.011	.099
Error	71.968	62	1.161			

Table 1.2 Paired sample T-test for an effect of disablers in each group.

	Mean	SD	SE Mean	t	df	p
ASD	-.038	.999	.196	-.196	25	.846
Typical	.974	1.793	.291	3.347	37	.002

Table 1.3 ANOVA performed on AC data from the conditional reasoning task in Experiment

1. 2x group 2x availability of alternatives

	SS	df	MS	F	p	η^2_p
Intercept	4239.944	1	4239.944	675.733	.000	.916
ALTERNATIVES	94.009	1	94.009	34.312	.000	.356
ALTERNATIVES* GROUP	22.852	1	22.852	8.341	.005	.119
Error	169.866	62	2.740			

Table 1.4 Paired sample T-test for an effect of alternatives in each group.

	Mean	SD	SE Mean	t	df	p
ASD	.885	2.123	.416	2.125	25	.044
Typical	2.605	2.477	.402	6.483	37	.000

Table 1.5 ANOVA performed on the P(q|p) data from the probability judgment task in Experiment 1. 2x availability of disablers 2x group

	SS	df	MS	F	p	η^2_p
Intercept	8883.076	1	8883.076	4271.958	.000	.986
DISABLERS	.805	1	.805	1.655	.203	.026
DISABLERS* GROUP	1.008	1	1.008	2.073	.155	.032
Error	30.147	62	.486			

Table 1.6 T-test of differences between ASD and typical groups on P(q|p) questions with low and high available disablers

	F	sig	t	df	p	Mean Diff	SE Diff
Low Disablers	1.927	.170	-.889	62	.377	-.25810	.29023
High Disablers	5.157	.027	.361	62	.738	.10324	.28628

Table 1.7 ANOVA performed on the P(p|q) data from the probability judgment task in Experiment 1. 2x availability of alternatives 2x group

	SS	df	MS	F	p	η^2_p
Intercept	7864.799	1	7864.799	2795.909	.000	.978
ALTERNATIVES	69.445	1	69.445	81.787	.000	.569
ALTERNATIVES* GROUP	1.641	1	1.641	1.932	.169	.030
Error	52.644	62	.849			

Table 1.8 T-test of differences between ASD and typical groups on P(p|q) questions with low and high available alternatives

	F	sig	t	df	p	Mean Diff	SE Diff
Low Alternatives	4.863	.031	-.543	62	.621	-.17156	.31605
High Alternatives	2.138	.149	.781	62	.438	.28947	.37058

Appendix B2 Experiment 2

Table 2.1 t-test of differences between groups in inference rates for standard or opposite conclusions on all argument forms.

	t	df	p	Mean Diff	SE Diff	Diff (lower)	Diff (upper)
MP standard	.490	56	.626	.045	.091	-.138	.228
MP opposite	-.722	56	.473	-.026	.036	-.099	.047
MT opposite	.337	56	.737	.039	.117	-.195	.274
MT standard	.432	56	.670	.097	.078	-.059	.253
AC standard	1.198	56	.327	.074	.061	-.049	.197
AC opposite	1.390	56	.330	.100	.072	-.044	.244
DA opposite	-.290	56	.773	-.039	.136	-.312	.233
DA standard	.223	56	.825	.021	.095	-.168	.211

Appendix B3 Experiment 3

Table 3.1 ANOVA (between subjects effects) performed on types of counterexamples generated by typical and ASD groups.

		SS	df	MS	F	P	η^2_p
Intercept	Type 1	7000.892	1	7000.892	458.294	.000	.902
	Type 2	.931	1	.931	3.862	.055	.072
	Type 3	248.539	1	248.539	109.230	.000	.686
	Type 4	15.404	1	15.404	19.614	.000	.282
GROUP	Type 1	1.508	1	1.508	.099	.755	.002
	Type 2	.008	1	.008	.032	.859	.001
	Type 3	.462	1	.462	.203	.654	.004
	Type 4	1.250	1	1.250	1.592	.213	.031
Error	Type 1	763.800	50	15.276			
	Type 2	12.050	50	.241			
	Type 3	113.769	50	2.275			
	Type 4	39.269	50	.785			

Table 3.2 ANOVA performed on data from the generation task in Experiment 3. 2x availability of disablers with group as a between-subjects factor.

	SS	df	MS	F	P	η^2_p
Intercept	1502.404	1	1502.404	401.176	.000	.889
DISABLERS	159.278	1	159.278	68.162	.000	.577
DISABLERS* GROUP	.509	1	.509	.218	.643	.004
Error	116.838	50	2.337			

Table 3.3 ANOVA performed on data from the generation task in Experiment 3. 2x availability of alternatives with group as a between-subjects factor.

	SS	df	MS	F	P	η^2_p
Intercept	1391.547	1	1391.547	400.532	.000	.889
ALTERNATIVES	427.778	1	427.778	278.819	.000	.848
ALTERNATIVES* GROUP	.009	1	.009	.006	.940	.000
Error	76.712	50	1.534			

Table 3.4 MANOVA performed on counterexamples generated for typical and autistic groups

	Value	F	Hypothesis df	Error df	p	η^2_p
Intercept	.910	2.471	2.000	49.000	.000	.910
GROUP	.013	.315	2.000	49.000	.731	.013

Table 3.5 Correlations between measure of influence of counterexamples on the conditional reasoning task and counterexamples generated by ASD and typical groups

		Counterexamples generated	
ASD	Measure of influence of counterexamples (conditional reasoning task)	Correlation	.163
		Sig (2 tailed)	.493
		N	20
Typical	Measure of influence of counterexamples (conditional reasoning task)	Correlation	.386*
		Sig (2 tailed)	.029
		N	32

Appendix B4 Experiment 4

Table 4.1 ANOVA For additional arguments in Experiment 4. 2x argument 2x validity and 2x endorsement with group as a between-subjects factor.

	SS	df	MS	F	p	η^2_p
Intercept	4197.612	1	4197.612	679.156	.000	.915
ARGUMENT	28.357	1	28.357	16.238	.000	.205
ARGUMENT* GROUP	3.557	1	3.557	2.037	.158	.031
Error	110.020	63	1.746			
VALIDITY	1.170	1	1.170	1.503	.225	.023
VALIDITY* GROUP	2.001	1	2.001	2.571	.114	.039
Error	49.030	63	.778			
ENDORSEMENT	26.899	1	26.899	19.463	.000	.236
ENDORSEMENT* GROUP	2.499	1	2.499	1.808	.184	.028
Error	87.070	63	1.382			
ARGUMENT* VALIDITY	.788	1	.788	1.249	.268	.019
ARGUMENT* VALIDITY* GROUP	3.557	1	3.557	5.642	.021	.082
Error	39.720	63	.630			
ARGUMENT* ENDORSEMENT	.942	1	.942	2.124	.150	.033
ARGUMENT* ENDORSEMENT* GROUP	.481	1	.481	1.084	.302	.017
Error	27.950	63	.444			
VALIDITY* ENDORSEMENT	.019	1	.019	.040	.843	.001
VALIDITY* ENDORSEMENT* GROUP	.173	1	.173	.358	.552	.006
Error	30.450	63	.483			
ARGUMENT* VALIDITY* ENDORSEMENT	.077	1	.077	.190	.664	.003
ARG* VALIDITY* ENDORSEMENT* GROUP	.077	1	.077	.190	.664	.003
Error	25.500	63	.405			

Table 4.2 ANOVA For alternative arguments in Experiment 4. 2x argument, 2x validity and 2x endorsement with group as a between-subjects factor.

	SS	df	MS	F	p	η^2_p
Intercept	3941.972	1	3941.972	960.724	.000	.938
ARGUMENT	82.127	1	82.127	56.583	.000	.473
ARGUMENT* GROUP	17.481	1	17.481	12.044	.001	.160
Error	91.442	63	1.451			
VALIDITY	55.973	1	55.973	39.833	.000	.387
VALIDITY* GROUP	1.096	1	1.096	.780	.380	.012
Error	88.527	63	1.405			
ENDORSEMENT	5.590	1	5.590	3.816	.055	.057
ENDORSEMENT* GROUP	.006	1	.006	.004	.950	.000
Error	92.302	63	1.465			
ARGUMENT* VALIDITY	66.602	1	66.602	67.278	.000	.516
ARG* VALIDITY* GROUP	1.125	1	1.125	1.137	.290	.018
Error	62.367	63	.990			
ARGUMENT* ENDORSEMENT	.592	1	.592	1.209	.276	.019
ARG* ENDORSEMENT* GROUP	.315	1	.315	.644	.425	.010
Error	30.877	63	.490			
VALIDITY* ENDORSEMENT	2.020	1	2.020	6.158	.016	.089
VALIDITY* ENDORSEMENT* GROUP	.097	1	.097	.297	.588	.005
Error	24.472	63	.388			
ARG* VALIDITY* ENDORSEMENT	.059	1	.059	.152	.698	.002
ARG* VAL* ENDORSEMENT* GROUP	.059	1	.059	.152	.698	.002
Error	24.472	63	.388			

Table 4.3 Paired sample t-test for effect of additional arguments on valid and invalid inferences for both groups

		Mean	SD	SE Mean	t	df	p
ASD	Valid additional arguments-Valid simple arguments	-.44000	2.21886	.44377	-.992	24	.331
	Invalid additional arguments-Invalid simple arguments	-.80000	2.23607	.44721	-1.789	24	.086
Typical	Valid additional arguments-Valid simple arguments	-1.80000	2.56405	.40541	-4.440	39	.000
	Invalid additional arguments-Invalid simple arguments	-.80000	1.63613	.25869	-3.092	39	.004

Appendix B5 Experiment 5

Table 5.1 ANOVA performed on data from Experiment 5. 2x availability of disablers, 2x condition with AQ and working memory (WM) as between-subjects factors.

	SS	df	MS	F	p	η^2_p
Intercept	1608.874	1	1608.874	330.095	.000	.885
DISABLERS	21.846	1	21.846	18.333	.000	.299
DISABLERS* AQ	.025	1	.025	.021	.884	.000
DISABLERS* WM	.033	1	.033	.028	.869	.001
DISABLERS* AQ* WM	3.272	1	3.272	2.746	.105	.060
Error	51.240	43	1.192			
CONDITION	.762	1	.762	1.289	.263	.029
CONDITION* AQ	.000	1	.000	.001	.980	.000
CONDITION* WM	.518	1	.518	.876	.354	.020
CONDITION* AQ* WM	.189	1	.189	.321	.574	.007
Error	25.414	43	.591			
DISABLERS* CONDITION	.053	1	.053	.153	.698	.004
DISABLERS* CONDITION* AQ	.389	1	.389	1.127	.294	.026
DISABLERS* CONDITION* WM	.389	1	.389	1.127	.294	.026
DISABLERS* CONDITION* AQ* WM	.053	1	.053	.153	.698	.004
Error	14.827	43	.345			

Table 5.2 ANOVA performed on data from Experiment 5. 2x availability of alternatives, 2x condition with AQ and working memory (WM) as between-subjects factors.

	SS	df	MS	F	p	η^2_p
Intercept	679.310	1	679.310	116.486	.000	.730
ALTERNATIVES	98.406	1	98.406	87.983	.000	.672
ALTERNATIVES* AQ	.210	1	.210	.188	.667	.004
ALTERNATIVES* WM	.008	1	.008	.007	.934	.000
ALTERNATIVES* AQ* WM	.114	1	.114	.102	.751	.002
Error	48.094	43	1.118			
CONDITION	1.944	1	1.944	2.783	.103	.061
CONDITION* AQ	.013	1	.013	.019	.891	.000
CONDITION* WM	.066	1	.066	.095	.760	.002
CONDITION* AQ* WM	.206	1	.206	.295	.590	.007
Error	30.040	43	.699			
ALTERNATIVES* CONDITION	.052	1	.052	.090	.766	.002
ALTERNATIVES* CONDITION* AQ	.882	1	.882	1.516	.225	.034
ALTERNATIVES* CONDITION* WM	.080	1	.080	.138	.712	.003
ALTERNATIVES* CONDITION* AQ* WM	.183	1	.183	.314	.578	.007
Error	25.023	43	.582			

Table 5.4 ANOVA performed on AC data from Experiment 5. 2x availability of alternatives
2x condition with attention to detail (AD) as a between-subjects factor.

	SS	df	MS	F	p	η^2_p
Intercept	675.078	1	675.078	118.167	.000	.724
ALTERNATIVES	100.657	1	100.657	102.322	.000	.695
ALTERNATIVES* AD	4.147	1	4.147	4.215	.046	.086
Error	44.268	45	.984			
CONDITION	1.883	1	1.883	2.830	.099	.059
CONDITION* AD	.393	1	.393	.591	.446	.013
Error	29.937	45	.665			
ALTERNATIVES* CONDITION	.056	1	.056	.098	.756	.002
ALTERNATIVES* CONDITION* AD	.651	1	.651	1.147	.290	.025
Error	25.551	45	.568			

Table 5.5 Correlations between effect of counterexamples (difference between numbers of endorsements where few and many counterexamples are available) and AQ subcategories.

Measure of the effect of counterexamples			
AQ subcategories	N	r	P
Social Skills	47	-.185	.214
Attention switching	47	-.211	.155
Attention to detail	47	-.298	.042
Communication	47	-.198	.181
Imagination	47	-.045	.765

Table 5.6 T-test of differences between high and low attention to detail groups on the effect of counterexamples for MP and AC

	F	sig	t	df	p	Mean Diff	SE Diff
Effect of counterexamples MP	2.939	.093	2.105	45	.041	.64583	.30678
Effect of counterexamples AC	.334	.566	2.053	45	.046	.59420	.28941

Table 5.7 ANOVA performed on response times for Experiment 5. 2x inference type, 2x condition with AQ as a between-subjects factor

	SS	df	MS	F	p	η^2_p
Intercept	17882.483	1	17882.483	119.586	.000	.727
INFERENCE TYPE	10.866	1	10.866	1.092	.302	.024
INFERENCE TYPE* AQ	1.610	1	1.610	.162	.689	.004
Error	447.747	45	9.950			
CONDITION	850.637	1	850.637	28.232	.000	.386
CONDITION* AQ	179.033	1	179.033	5.942	.019	.117
Error	1355.880	45	30.131			
INF TYPE* CONDITION	57.352	1	57.352	4.086	.049	.083
INF TYPE* CONDITION* AQ	2.044	1	2.044	.146	.705	.003
Error	631.660	45	14.037			

Table 5.8 Paired sample t-test comparing response times under tapping and articulation for low and high AQ participants

AQ		Mean	SD	SE Mean	t	df	p
low	RT under articulation-RT under tapping	-6.20738	7.06230	1.47259	-4.215	22	.000
high	RT under articulation-RT under tapping	-2.30305	3.35317	.68446	-3.365	23	.003

Table 5.9 t-test comparing low and high AQ groups on difference between RT for tapping and RT for articulation

	F	sig	t	df	p	Mean Diff	SE Diff
Difference in RT between tapping and articulation	1.838	.182	2.058	45	.045	3360.85009	1632.88511

Appendix B6 Experiment 6

Table 6.1 ANOVA on data from Experiment 6. 2x availability of disablers 2x condition with type of load as between-subjects factor.

	SS	df	MS	F	P	η^2_p
Intercept	3675.862	1	3675.862	1540.550	.000	.948
DISABLERS	19.815	1	19.815	35.905	.000	.297
DISABLERS* TYPE OF LOAD	.045	1	.045	.081	.776	.001
Error	46.909	85	.552			
CONDITION	.126	1	.126	.121	.729	.001
CONDITION* TYPE OF LOAD	3.114	1	3.114	2.991	.087	.034
Error	88.495	85	1.041			
DISABLERS* CONDITION	.832	1	.832	1.817	.181	.021
DIS* CONDITION* TYPE OF LOAD	.004	1	.004	.009	.925	.000
Error	38.915	85	.458			

Table 6.2 ANOVA on data from Experiment 6. 2x availability of disablers 2x condition with type of load and working memory groups (low/very high) as between-subjects factors.

	SS	df	MS	F	p	η^2_p
Intercept	2708.287	1	2708.287	1111.414	.000	.931
DISABLERS	11.695	1	11.695	21.089	.000	.203
DISABLERS* TYPE OF LOAD	.055	1	.055	.100	.753	.001
DISABLERS* WM	.467	1	.467	.842	.362	.010
DISABLERS* TYPE OF LOAD* WM	.523	1	.523	.942	.335	.011
Error	46.030	83	.555			
CONDITION	.216	1	.216	.208	.649	.003
CONDITION* TYPE OF LOAD	3.744	1	3.744	3.604	.061	.042
CONDITION*WM	2.104	1	2.104	2.026	.158	.024
CONDITION* TYPE OF LOAD* WM	.356	1	.356	.342	.560	.004
Error	86.216	83	1.039			
DISABLERS* CONDITION	.202	1	.202	.436	.511	.005
DISABLERS* CONDITION* TYPE OF LOAD	.061	1	.061	.131	.718	.002
DISABLERS* CONDITION* WM	.343	1	.343	.742	.391	.009
DIS* CONDITION* LOAD* WM	.256	1	.256	.554	.459	.007
Error	38.382	83	.462			

Table 6.3 ANOVA on data from Experiment 6. 2x availability of alternatives 2x condition with type of load as between-subjects factor.

	SS	df	MS	F	p	η^2_p
Intercept	2001.854	1	2001.854	458.800	.000	.844
ALTERNATIVES	187.570	1	187.570	143.829	.000	.629
ALTERNATIVES* TYPE OF LOAD	5.547	1	5.547	4.253	.042	.048
Error	110.850	85	1.304			
CONDITION	.825	1	.825	.862	.356	.010
CONDITION* TYPE OF LOAD	.066	1	.066	.069	.793	.001
Error	81.353	85	.957			
ALTERNATIVES* CONDITION	1.288	1	1.288	1.730	.192	.020
ALT* CONDITION* TYPE OF LOAD	.668	1	.668	.896	.346	.010
Error	63.315	85	.745			

Table 6.4 Correlations between effect of counterexamples (difference between numbers of endorsements where few and many counterexamples are available) and AQ subcategories, in the simple and complex conditions.

		Measure of the effect of counterexamples		
	AQ subcategories	N	r	p
Simple condition	Social Skills	44	.171	.133
	Attention switching	44	-.008	.481
	Attention to detail	44	-.136	.190
	Communication	44	.131	.199
	Imagination	44	.172	.132
Complex condition	Social Skills	43	.046	.384
	Attention switching	43	-.167	.143
	Attention to detail	43	-.259	.047
	Communication	43	.058	.355
	Imagination	43	.032	.418

Table 6.5 Moderated regression with effect of counterexamples as the dependent variable, attention to detail and working memory as predictors

	Unstandardised		Standardised		
	coefficients		coefficients		
		SE	Beta	t	sig
Constant	.904	.110		8.194	.000
Attention to detail	-.134	.052	-.375	-2.562	.014
Working memory	.001	.011	.012	.079	.937
Attention to detail* working memory	-.014	.005	-.428	-2.739	.009

Dependent variable: effect of counterexamples

Table 6.6 ANOVA (within-subjects effects) on response time data from Experiment 6. 2x inference type 2x availability of counterexamples 2x condition with type of load as a between-subjects factor

	SS	df	MS	F	p	η^2_p
INFERENCE TYPE	16.234	1	16.234	1.074	.303	.012
INFERENCE * TYPE OF LOAD	14.701	1	14.701	.973	.327	.011
Error	1284.422	85	15.110			
AVAILABILITY	16.087	1	16.087	1.051	.308	.012
AVAILABILITY* TYPE OF LOAD	6.163	1	6.163	.403	.527	.005
Error	1301.398	85	15.310			
CONDITION	84.387	1	84.387	3.451	.067	.039
CONDITION* TYPE OF LOAD	1.261	1	1.261	.516	.475	.006
Error	2078.278	85	24.450			
INFERENCE* AVAILABILITY	2.145	1	2.145	.177	.675	.002
INF* AVAILABILITY* LOAD	.958	1	.958	.079	.779	.001
Error	1027.391	85	12.086			
INFERENCE TYPE* CONDITION	2.765	1	2.765	.229	.634	.003
INF* CONDITION* TYPE OF LOAD	1.213	1	1.213	.100	.752	.001
Error	1028.531	85	12.100			
AVAILABILITY* CONDITION	1.758	1	1.758	.155	.695	.002
AVAIL* CONDITION* LOAD	5.805	1	5.805	.511	.477	.006
Error	966.567	85	11.371			
INF * AVAIL* CONDITION	2.161	1	2.161	.225	.637	.003
INF* AVAIL* CONDITION* LOAD	5.269	1	5.269	.548	.461	.006
Error	817.139	85	9.613			

Table 6.7 Between-subjects tables of effects for ANOVA on response time data from Experiment 6. 2x inference type 2x availability of counterexamples 2x condition with type of load as a between-subjects factor

Tests of between-subjects effects						
Source	SS	df	MS	F	p	η^2_p
Intercept	13885.632	1	13885.632	314.006	.000	.787
TYPE OF LOAD	181.381	1	181.381	4.102	.046	.046
Error	3758.775	85	44.220			

Table 6.8 ANOVA (within-subjects effects) on response time data from the simple condition in Experiment 6. 2x inference type 2x condition with AQ as between-subjects factor.

	SS	df	MS	F	p	η^2_p
Intercept	2754.915	1	2754.915	278.479	.000	.869
INFERENCE TYPE	.010	1	.010	.008	.931	.000
INFERENCE TYPE* AQ	1.635	1	1.635	1.283	.264	.030
Error	53.538	42	1.275			
CONDITION	41.036	1	41.036	3.241	.079	.072
CONDITION* AQ	19.834	1	19.834	1.567	.218	.036
Error	531.759	42	12.661			
INF* CONDITION	1.932	1	1.932	.904	.347	.021
INF* CONDITION* AQ	3.681	1	3.681	1.722	.197	.039
Error	413.910	41	10.095			

Table 6.9 Table of between-subjects effects for ANOVA on response time data from the simple condition in Experiment 6. 2x inference type 2x condition with AQ as between-subjects factor.

Tests of between-subjects effects						
Source	SS	df	MS	F	p	η^2_p
Intercept	2754.914	1	2754.914	278.479	.000	.869
AQ	57.342	1	57.342	5.796	.021	.121
Error	415.494	42	9.892			

Paper in press

Accepted June 22, 2009

Developmental Psychology

2009, Vol. *45*, No. *3*, 000–000

**Conditional reasoning in autism: activation and integration of
knowledge and belief.**

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Abstract

Everyday conditional reasoning is typically influenced by prior knowledge and belief in the form of specific exceptions known as counterexamples. This study explored whether adolescents with Autism Spectrum Disorder (ASD) (N=26) were less influenced by background knowledge than typically developing adolescents (N=38) when engaged in conditional reasoning. Participants were presented with pretested valid and invalid conditional inferences with varying available counterexamples. The group with ASD showed significantly less influence of prior knowledge on valid inferences ($p = .01$) and invalid inferences ($p = .01$) compared to the typical group. In a secondary probability judgment task, no significant group differences were found in probabilistic judgments of the believability of the premises. Further experiments found that results could not be explained by differences between the groups in the ability to generate counterexamples or any tendency among adolescents with ASD to exhibit a yes response pattern. It was concluded that adolescents with ASD tend not to spontaneously contextualize presented material when engaged in everyday reasoning. These findings are discussed with reference to Weak Central Coherence Theory and the conditional reasoning literature.

Four decades of research into adult deductive reasoning has shown that participants are highly influenced by the content and context used to frame problems (Evans, 2002). Such effects are typically referred to in this literature as a cause of 'cognitive bias', since participants are routinely instructed to draw only necessary conclusions based on the information given. Arguably, this is a paradigm-bound perspective as the ability to take account of background knowledge and belief in everyday reasoning is highly adaptive and instrumental in achieving our personal goals (Evans, 2007). In this study, we test the hypothesis that the reasoning of adolescents with Autistic Spectrum Disorder (ASD) will be less contextualized than that of a typically developing control group. We do this with reference to the study of conditional reasoning, with 'if-then' arguments, as much is already known about the influence of prior knowledge on this task (Evans, 2007; Evans & Over, 2004).

Conditional reasoning involves inference with a major premise of the form 'if p then q' and four possible minor premises. In the case of Modus Ponens (MP) this involves reasoning from the premises 'if p then q, p is true,' this leads logically to the response 'p is true.' Modus Tollens (MT) requires reasoning from the premises 'if p then q, q is false' leading logically to the conclusion 'p is false.' Both MP and MT are valid inferences in that there is a single logically correct response. Affirmation of the Consequent (AC) requires reasoning with the premises 'if p then q, q is true. Denial of the Antecedent (DA) requires reasoning with the premises 'if p then q, p is false.' AC and DA are invalid inferences in the sense that the correct logical response is one of uncertainty. Here the implied responses are not logically correct, although there is a tendency for people to respond with certainty by giving the pragmatically implied conclusion 'p is true' for AC and 'q is false' for DA.

Context in the form of disabling conditions and alternative antecedents, collectively known as counterexamples, have been shown to influence the tendency to endorse both valid and invalid conclusions (e.g., Cummins, 1995; Cummins et al., 1991; Quinn & Markovits, 1998; Thompson, 1994). It has been claimed that willingness to endorse arguments is

influenced by the extent to which knowledge about counterexamples is activated and integrated with premise information. Consider the following example of a MP argument (Markovits & Porvin, 2001).

If a chair is thrown at a window, then the window will break

Suppose a chair is thrown at the window, does it follow that the window is broken?

Whilst the conclusion follows logically in this case, many participants will withhold the inference because there are many available exceptions. They may think of specific conditions in which the effect does not follow from the cause (e.g. the window is made of toughened glass or the chair is made of plastic etc.) In the case of valid inferences these exceptions or counterexamples are known as disabling conditions. The activation and integration of such disablers increases the tendency for people to withhold the inference.

Similarly if we consider the invalid AC form:

Suppose the window is broken, does it follow that a chair was thrown at the window?

Whilst reasoners often endorse the AC conclusion, in this example there are many counterexamples in the form of alternative antecedents or causes which would lead to the same effect (such as throwing a rock or a cricket ball at the window). In the case of invalid inferences, where alternatives are available, people are more likely to give the correct logical 'uncertainty' response to this argument form. The influence of context on conditional reasoning is, therefore, distinct from logical reasoning ability since the impact of knowledge on valid and invalid inferences acts both to suppress and facilitate logical reasoning.

This account assumes that specific counterexamples are activated and integrated with premise information. Recent evidence suggests that conditional reasoning can also be influenced by more automatic associative belief based processes, consistent with dual-processing accounts of reasoning (Evans, 2008). The associative processes underlying probabilistic judgments, for example, have been shown to have a distinct influence on

conditional reasoning that is partially independent of the influence of retrieved counterexamples (Weidenfield, Oberauer & Hornig, 2005).

The influence of background knowledge on reasoning is subject to development (Janveau-Brennan & Markovits, 1999; Klaczynski, Schuneman & Daniel, 2004; Markovits & Thompson, 2008; Muller, Overton & Reene, 2001) and in children, at least, involves effortful processes (Morsanyi & Handley, 2008). Although children as young as 4 years of age can draw valid inferences when presented with familiar content (Dias & Harris, 1990; Markovits, 2000), very young children show little effect of background knowledge (Markovits & Barrouillet, 2002). Contextualised reasoning among typically developing youngsters, develops through late childhood into adolescence. There are a number of reasons why this is the case (Markovits & Barrouillet, 2002; Markovits, Fleury, Quinn & Venet, 1998; Markovits & Thompson, 2008). Young children simply have less background knowledge available in long term memory. Retrieval of information is also less efficient in younger children compared to adolescents. Critically children's contextualized reasoning performance is also related to the cognitive demands of representational processes. Young children are limited in the complexity of the models they are capable of forming and for very young children reasoning relies predominantly on the consideration of the major premise presented (Markovits & Barrouillet, 2002). Children tend to interpret inferences biconditionally (if and only if p then q). The ability to respond with uncertainty to invalid inferences does not reliably appear until adolescence (Muller et al. 2001). Not until around 11 years are children able to respond with uncertainty to DA as well as AC, this is accompanied by relatively high reference to counterexamples as justifications and denial of MP in some cases (Markovits & Janveau-Brennan, 1999).

Developmental factors seem to specifically impact on the cognitively demanding consideration of counterexamples in conditional reasoning. Typically developing 6 year olds are able, for example, to make probabilistic judgments about conditional statements but find it difficult to draw on background knowledge when engaged in everyday reasoning, even when

such information is actively presented (Markovits and Thompson, 2008). As adolescents move towards adulthood, the development of inhibitory and meta-cognitive processes allows for more control over reasoning and a more selective use of background knowledge (Markovits & Barrouillet, 2002; 2004; Muller et al. 2001). Typically developing adolescents, therefore, present a population which is arguably more influenced by background knowledge compared to younger children and adults.

While studies of the development of conditional reasoning have tended to focus on typically developing groups, the information processing style of individuals with ASD suggests that their reasoning processes may differ in significant ways. A number of current theories about the nature of autism explore the difficulties people with ASD may have with contextualizing or integrating information. Weak Central Coherence Theory (Frith, 1989; 2003; Happé & Booth, 2008; Happé & Frith, 2006) proposes that human beings have an inherent drive towards central coherence, the formation of coherent wholes through the integration of pieces of relevant information. Incoming stimuli tend to be processed in context in order to derive a meaningful gist of the situation, often at the expense of surface details. Frith claims that individuals with ASD differ from the typical population in exhibiting a tendency towards weak central coherence, which results in an over reliance on local or piecemeal processing and a tendency not to integrate information in order to process stimuli in context.

The tendency towards weak central coherence in populations with ASD has been demonstrated across a number of domains. This processing style results in good performance in tasks which rely upon the identification of localized details, such as the Embedded Figures Task, (Frith, 1989), Block Design Test (Shah & Frith, 1993) and perceptual learning tasks (Plaisted, O'Riordan, & Baron-Cohen, 1998), but results in poor performance on tasks which require the integration of details such as the disambiguation of homographs (Frith &

Snowling, 1983; Jolliffe & Baron-Cohen, 1999a) and the interpretation of words in ambiguous sentences (Jolliffe & Baron-Cohen, 1999b).

Little is known about the conditional reasoning performance of individuals with ASD. One recent study (Pijnacker et al., 2009) explored the ability of high functioning adults with autism to revise conditional reasoning conclusions on the basis of new contextual information in the form of a secondary conditional statement. Participants with autism showed no significant differences in performance compared to controls on simple conditional reasoning tasks with valid and invalid inferences. Where extra conditional statements were presented the participants with autism were found to exhibit a specific difficulty with exception-handling resulting in a tendency not to revise conclusions on valid inferences. Analysis of reasoning outcomes focused on logically correct rather than invited responses. Consideration of endorsement responses for invalid inferences suggests, however, that the presentation of extra information influenced the reasoning responses of typical participants to a greater extent than participants with autism for both valid and invalid inferences.

It has been repeatedly shown that typically developing populations tend to contextualize presented information when they reason. This is particularly true of typically developing adolescents compared to younger children and adults. At the same time there is a growing body of research which suggests that individuals with ASD have difficulty integrating information in order to process stimuli in context. The explicit influence of background knowledge on conditional reasoning relies upon the activation of specific exceptions available in long term memory and the integration of such counterexamples with presented stimuli. We surmised that difficulties with integrating information and impairment in contextualized thinking would, therefore, result in a tendency among adolescents with ASD to be less influenced by counterexamples compared to controls when engaged in conditional reasoning.

In Experiment 1 we manipulated the availability of disablers and alternative antecedents on conditional reasoning problems. As suggested by the work of Pijnacker et al. (2009), we

anticipated that individuals with ASD would be able to engage in simple conditional reasoning tasks and show similar patterns of response to typical controls where counterexamples were not available. Where counterexamples were available we predicted that our group with ASD would be less influenced by disabling conditions on MP compared to controls and would not show the typical decreased tendency to accept the logically correct conclusion. We also predicted that the adolescents with ASD would be less influenced by alternative causes on AC compared to the typical group and would not exhibit the usual increased tendency to give the logically correct uncertainty response.

Background knowledge in the form of counterexamples can both facilitate and suppress logical reasoning performance. The presentation of both valid and invalid inferences allowed us, therefore, to examine the effect of context on reasoning outcomes controlling for any group differences in logical reasoning ability. In addition, a probability judgment task was included, which allowed us to measure the relevant associative beliefs concerning the relation expressed in each conditional statement, in order to ensure that any differential effects of counterexamples between the two groups could not be attributed to differences in underlying beliefs. Further possible differences between the two groups likely to affect reasoning outcomes were explored in Experiments 2 and 3. In Experiment 2 we investigated whether the adolescents with ASD were more likely to habitually give affirmative responses to reasoning problems compared to the typically developing participants. In Experiment 3 we compared the ability of typically developing adolescents and the group with ASD to generate counterexamples.

Experiment 1

Experiment 1 examined conditional reasoning and probabilistic judgments in relation to available counterexamples. Adolescents with ASD and a typically developing control group performed a conditional reasoning task, where statements had varying available disabling

conditions and alternative antecedents. This task was followed by a likelihood judgment task, in which participants were asked to rate the believability of the statements presented.

Method

Participants

Participants included 26 adolescents with ASD and 38 typically developing adolescents. The adolescents with ASD were between the ages of 11 and 16 years. The typically developing adolescents were between the ages of 11 and 15. Participants were recruited by approaching mainstream schools with special units supporting pupils on the autistic spectrum. In the group with ASD only those adolescents were included who had a definitive clinical diagnosis of autism spectrum disorder meeting criteria from the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.; DSM-IV; American Psychiatric Association, 1994) or *International Classification of Diseases* (10th ed; ICD-10; World Health Organization, 1993). Diagnoses were carried out by either a paediatrician or child and adolescent psychiatrist following multidisciplinary assessment. Adolescents with ASD with either a medical diagnosis such as epilepsy or a neurodevelopmental diagnosis other than autism such as attention deficit hyperactivity disorder, or who were taking medication, were excluded from the study. There were 21 boys and 5 girls in the group with ASD. There were 23 boys and 15 girls in the typically developing group. There were 22 high functioning adolescents diagnosed as having autism and 4 adolescents diagnosed with asperger syndrome. Within the typically developing group children were excluded if they had a diagnosis of autism, asperger syndrome or were documented as having autistic traits. Children who had a statement of special educational needs were also excluded.

Typically developing participants and those with ASD were recruited from the same mainstream schools in lower middle class urban areas within Plymouth and West Devon. All

of the teenagers who took part in the study were white, predominantly lived in urban areas and English was the first language for all of the participants.

All participants were given a range of tests measuring participant characteristics, including a non verbal working memory task (adapted from Wilson, Bettger, Nicolae & Klima, 1997). Our task differed from that of Wilson et al. in that it included processing and storage elements. Participants had to recall, in sequence, the location of a series of blocks. In addition to the span task, participants were also required to recall the final location of the previous trial sequences. Scores represent, therefore, a measure of the ability to process and store given information. Working memory was measured as it has been shown to be highly correlated with general intelligence (Colom, Rebollo, Palacios, Juan-Espinosa & Kyllonen, 2004) and has also been implicated in conditional reasoning performance (e.g. De Neys, Schaeken, & d'Ydewalle, 2005; Verschueren et al., 2004; Verschueren et al., 2005). Variations in working memory have, for example, been shown to influence the strategies reasoners employ and consequent reasoning outcomes (Verschueren et al., 2005).

Participants were also given The Stop-Signal Task (Logan, Schachar, & Tannock, 1997), taken to measure inhibition. A measure of inhibition was included since inhibitory processes are proposed to mediate reasoning performance through individual differences in the selective suppression of competing responses (De Neys et al., 2005). If our two groups were found to differ on measures of inhibition this could, therefore, be an underlying factor in their ability to selectively use background knowledge in reasoning. The Stop-Signal Task requires participants to suppress a prepotent response (pressing a button in response to a tone). Scores represent the overall number of correct responses to stop signal trials across a number of different time delays between the presentation of the tone and the stimuli.

The expressive vocabulary test of The Wechsler Intelligence Test for Children (WISC-III, Wechsler, 1991) was also given to all participants. The WISC expressive vocabulary test was chosen as it was felt to be of importance that the two groups were comparable on their ability

to understand the terms used within the given problems. This subtest measures verbal concept formation, fund of knowledge and degree of language development.

Adolescents were excluded if they scored two standard deviations above or below the mean scaled score for their age group on the WISC expressive vocabulary measure. Scores above or below these points were deemed unacceptable as they reflected unusually high or low ability for any given age range. Excluded individuals had scores which were the same as, higher than 2% of a given age range or lower than 2% of a given age range. Participants were also excluded if they failed to score on the storage or processing elements of the working memory task.

Adolescents with ASD were matched as closely as possible with the typically developing adolescents on the basis of the individual differences measures and chronological age (See Table 1). No significant differences between the two groups were found for chronological age ($t(62) = 1.07$ $p = .29$), age corrected standard vocabulary scores ($t(62) = -1.02$ $p = .31$), working memory span ($t(62) = -0.44$ $p = .66$), or inhibition ($t(62) = -0.81$ $p = .42$).

(Put Table 1 here)

A separate sample was used to pretest reasoning materials. The children included in the pretest were recruited from a mainstream school in the Plymouth area of Southern England with a lower middle class catchment profile. This school was also used to recruit adolescents with ASD in Experiments 1, 2 and 3. As such, the pretest group was deemed to be from similar educational and socioeconomic backgrounds as subsequent participants. The pretest group included typically developing adolescents with a range of educational abilities. Any child with a diagnosis for autism or asperger syndrome or a statement of special educational needs was excluded from the pretest group. Since we wanted to ensure that differences in availability of counterexamples in the statements used would be discernable even by the youngest children in further experiments, the children were recruited from the youngest age range included in our subsequent experiments and were between 11 and 12 years of age.

Materials and procedure

Pretest

Forty questions were largely drawn from Cummins et al. (1991). In this study pretested conditional statements were presented which were known to vary in the number of alternative antecedents and disabling conditions available relating to the causal relationship. The purpose of the pretest was to categorise materials for use in later experiments as having either low or high available counterexamples. Since the Cummins et al. study used adult participants some additional questions were adapted for a younger audience. The questions were piloted with forty typically developing adolescents in four groups of ten in order to establish four groups of statements with:

- High numbers of disabling conditions and high numbers of alternative antecedents, for example: *If a mug is dropped, then it will break.*
- High numbers of disabling conditions and low numbers of alternative antecedents, for example: *If the trigger is pulled, then the gun will fire.*
- Low numbers of disabling conditions and high numbers of alternative antecedents, for example: *If a balloon is pricked, then it will burst.*
- Low numbers of disabling conditions and low numbers of alternative antecedents, for example: *If butter is heated, then it will melt.*

Each group of 10 children was presented with 10 MP and 10 AC conditionals. The children were asked to generate as many counterexamples as possible, for each question, in one and a half minutes. Mean numbers of alternatives and disablers were calculated for each conditional. These means were split into quartiles, and 4 groups of 4 conditionals chosen, which best fitted the required high-low categories. Mean numbers of alternatives and disablers for each of the 4 categories listed above are shown in Table 2.

(Put Table 2 here)

Conditional reasoning task

There were 32 questions in the reasoning task, 16 MP and 16 AC statements, four from each of the pretest high-low categories (See Appendix). The task was presented by an animated robot on a computer screen. Participants were presented with brief pragmatic instructions as follows:

In this task you will be shown some statements. After each statement there will be a fact and a conclusion. Given the statement and the fact, you need to make a decision about whether the conclusion follows.

The participants were then presented with two practice questions, one of each inference type. Feedback was given to ensure that participants understood the task. The experimental statements were then presented in a random order. Questions remained on the screen until the participant responded. All questions were presented as a statement, an invitation to suppose a fact, and a question about what follows, for example: "If the ignition key is turned, then the car will start. Suppose the ignition key is turned, Does it follow that the car will start?" Participants were required to respond by pressing one of two buttons, labelled '**YES, definitely**' and '**NO, not necessarily.**' The correct logical responses for MP questions being 'Yes, definitely' and for AC being 'No, not necessarily.'

Probability judgment task

The probability judgment task was included to measure the relevant associative beliefs concerning the relation expressed in each conditional statement. The purpose of the task was to ensure that any differential effects of counterexamples between the two groups could not be attributed to differences in underlying beliefs.

Participants were presented with the 16 conditionals used in the inference part of the study and asked to rate the likelihood of the consequent in the light of the antecedent. The conditionals either expressed forward causality (if cause then effect, $P(q|p)$) or backward

causality (if effect then cause, $P(p|q)$), the probability judgments relevant to the MP and AC inferences respectively, giving a total of 32 questions. The task was presented on a computer screen by the animated robot used in the conditional reasoning task. Participants were given the following instructions:

On the following screens you will see some statements. You will be asked how likely each statement is. You will have to rate how likely the event is by clicking a number from 1 to 5.

Participants were then shown an example question and the scale. They were told that clicking on number one meant 'not very likely' and five meant 'very likely'. The statements were then presented in a random order. Questions remained on the screen until the participant responded. The participants were given two practice questions. All questions were presented in the following format:

How likely is it that

If a towel is dropped in the bath, then it will get wet?

Not likely 1 2 3 4 5 Very likely

Results

Conditional reasoning task

A 2 (group) by 2 (low vs high disablers) repeated measures Anova was performed on the MP inference data from the conditional reasoning task. Mean endorsement responses for MP questions, comparing autistic and typical groups are shown in Figure 1. The analysis revealed a main effect of disablers ($F(1,62) = 5.82, MSE = 1.16, p = .02, \eta^2_p = .09$) and a significant two-way interaction between disablers and group ($F(1,62) = 6.81, MSE = 1.16, p = .01, \eta^2_p = .10$), such that disablers affected the reasoning of the typical adolescents more than the adolescents with ASD (See Figure 1).

(Put Figure 1 here)

In order to provide further information about the interaction between group and disablers, we performed paired sample *t* tests to test for an effect of disablers in each group. These showed a significant difference in endorsement rates on MP between high and low disabler questions among the typically developing group ($t(37) = -3.35$ $p = .002$) but no significant difference in endorsement rates among the group with ASD ($t(25) = -0.20$ $p = .85$).

A second Anova was performed to examine the effect of alternatives (high vs. low) on AC inferences, with autism as a between subjects factor. Mean endorsement responses for AC questions, comparing autistic and typical groups are shown in Figure 2. The analysis revealed a main effect of alternatives ($F(1,62) = 34.31$, $MSE = 2.74$, $p < .001$ $\eta^2_p = .36$). Again, the predicted significant two-way interaction was found between alternatives and group ($F(1,62) = 8.34$, $MSE = 2.74$, $p = .01$ $\eta^2_p = .12$), reflecting greater use of alternatives in the typically developing group (see Figure 2).

(Put Figure 2 here)

Once again, follow-up *t* tests were performed to check for an effect of alternatives in the two groups separately. In this case, paired sample *t* tests showed a significant difference in endorsement rates on AC between high and low alternative questions for both groups. Consistent with the significant interaction, this trend was considerably more marked in the typical group ($t(37) = -6.48$ $p < .001$), than in the group with autism ($t(25) = 2.03$ $p = .04$).

Probability judgment task

A 2 (group) by 2 (low vs high disablers) repeated measures Anova was performed on the $P(q|p)$ data from the probability judgment task. The main effect of disablers was not found to be significant ($F(1,62) = 1.66$, $MSE = 0.49$, $p = .20$ $\eta^2_p = .03$). The two-way interaction between disablers and autism was also not found to be significant ($F(1,62) = 2.07$, $MSE =$

0.49 $p = .16$ $\eta^2_p = .03$), such that disablers did not affect likelihood judgments for either group).

Follow-up t tests revealed that there were no significant differences between autistic and typical groups on $P(q|p)$ questions with low available disablers ($t(62) = -0.89$ $p = .38$) or $P(q|p)$ questions with high available disablers ($t(62) = 0.36$ $p = .74$).

A 2 (group) by 2 (low vs high alternatives) repeated measures Anova was also performed on the $P(p|q)$ data from the probability judgment task. The main effect of alternatives was found to be significant ($F(1,62) = 81.79$, $MSE = 0.82$, $p = < .001$ $\eta^2_p = .57$). The two-way interaction between alternatives and autism was, however, not found to be significant ($F(1,62) = 1.93$, $MSE = 0.85$, $p = .17$ $\eta^2_p = .03$), such that available alternatives affected likelihood judgments for both groups.

Follow-up t tests once again revealed that there were no significant differences between autistic and typical groups on $P(p|q)$ questions with low available alternatives ($t(62) = -0.54$ $p = .62$) or $P(p|q)$ questions with high available alternatives ($t(62) = 0.78$ $p = .44$).

Discussion

In line with previous research, typically developing adolescents showed a significant effect of available counterexamples on conditional reasoning. The typical group were more likely to withhold MP, where there were higher numbers of available disabling conditions, and more likely to give uncertainty responses to AC, where there were high numbers of alternative antecedents. Our hypothesis that this pattern of responding would not be mirrored by the autistic group was confirmed. For both inferences we observed significant interactions, indicating that background knowledge had less influence on the reasoning of the adolescents with ASD. The possibility that the difference in performance between the two groups was driven by group differences in the believability of the conditional statements was eliminated.

No significant group differences were found in probabilistic judgments of the believability of the premises.

The conditional reasoning data are consistent with our general hypothesis that the reasoning of adolescents with ASD is less likely to be contextualized with relevant background knowledge. An alternative explanation for the results of the conditional reasoning task relates to the pattern of responses given by the adolescents with ASD. Although the correct logical response for the invalid inference AC is one of uncertainty, there is a tendency for people to respond with certainty to invalid inferences where little background knowledge is available. This is reflected in the high numbers of endorsements by both groups in response to AC questions with few alternative antecedents. Since the correct logical response for MP is also to endorse the inference, there is a tendency among typical populations for affirmative responses to be given to both MP and AC when reasoning outside of empirical knowledge. This pattern of responding is also shown by the participants with ASD where available counterexamples are low. Where background knowledge is available, typical groups are less likely to endorse MP and AC and hence give less affirmative responses for both inferences. It is possible that the adolescents with ASD do not show this drop in affirmative responding because they simply have a stronger tendency to respond by saying yes. There is some previous evidence that younger children with autism exhibit a yes bias when engaged in contrary-to-fact reasoning tasks (Leavers and Harris, 2000). Contrary-to-fact reasoning is very different from the kind of everyday conditional reasoning presented here. It is possible, nevertheless, that a yes response bias could explain the findings of Experiment 1. An additional experiment was carried out to examine this possibility.

Experiment 2

The purpose of Experiment 2 was to explore the possibility that the pattern of responding exhibited by the adolescents with ASD in Experiment 1 was related to a generalised yes

response bias. Adolescents with ASD and typically developing adolescents were given a reasoning task with equal numbers of affirmative and negative correct responses.

Method

Participants

As far as possible the participants reflected the same populations as in Experiment 1. The adolescents were recruited from the same schools and within the same age range. 20 adolescents with ASD, 14 of which had taken part in Experiment 1 and 38 typically developing adolescents were included in the study. The adolescents in both groups were between the ages of 11 and 16. There were 16 boys and 4 girls in the group with ASD and 21 boys and 17 girls in the typical group. All of the adolescents with ASD had a clinical diagnosis of autism spectrum disorder meeting either DSM-IV (APA, 1994) or ICD-10 (WHO, 1993) criteria. Diagnoses were performed by either a paediatrician or child and adolescent psychiatrist following multidisciplinary assessment. Adolescents with ASD with either a medical diagnosis such as epilepsy or a neurodevelopmental diagnosis other than autism such as attention deficit hyperactivity disorder, or who were taking medication, were excluded from the study. There were 17 high functioning adolescents diagnosed as having ASD or autism and 3 adolescents diagnosed with asperger syndrome. Within the typically developing group children were excluded if they had a diagnosis of autism spectrum disorder, asperger syndrome or were documented as having autistic traits. Children who had a statement of special educational needs were also excluded. Recruitment was from mainstream schools in lower middle class urban areas within Plymouth and West Devon. All of the teenagers who took part in the study were white, predominantly lived in urban areas and English was the first language for all of the participants.

All participants were given a measure of Working Memory based on that developed by Case, Kurland and Goldberg (1982) incorporating a processing and storage component and a

subtest of The Wechsler Intelligence Test for Children (WISC-III, Wechsler, 1991) measuring expressive vocabulary. The reasoning task used in this experiment differed from the one presented in Experiment 1 in that it did not involve potentially conflicting analytical and empirical responses. For this reason a measure of inhibition was not included in the measures of participant characteristics. No significant differences between groups were found (See Table 3) for chronological age ($t(56) = 0.69$ $p = .49$), age corrected standard vocabulary scores ($t(56) = -1.55$ $p = .13$) or working memory span ($t(56) = -1.75$ $p = .09$).

(Put Table 3 here)

Materials and procedure

The participants were presented with simple arguments based on a universally quantified major premise. The structure of the questions was taken from the Leever and Harris (2000) study which found evidence for a yes response bias in children with ASD. The content differed from that used by Leever and Harris, however, in that the questions were not contrary-to-fact. The materials used were similar in content to the problems in Experiment 1, in so far as the questions referred to familiar everyday information which did not conflict with empirical knowledge.

Sixteen questions were presented, four of each type of inference (MP, MT, AC and DA). For each inference there were two questions with standard affirmative conclusions, where drawing the inference involves responding 'yes', for example: "All birds have feathers. Robins are birds. Does it follow that robins have feathers?" And 2 questions with opposite conclusions, where drawing the inference involves responding 'no', for example: "All fires are hot. A bonfire is a fire. Does it follow that a bonfire is cold?" If the participants with ASD exhibit a bias to say 'yes' then this will be manifested in reduced rate of drawing the inference on problems with opposite conclusions. The questions were presented in a booklet. All materials were read out loud by the experimenter and participants were required to circle either a 'yes' or 'no' response. Participants were tested in small groups of up to 5 individuals.

Results

Table 4 shows rates of inference for the four argument forms under standard and opposite conclusions for the two groups. The presence of a bias to respond 'yes' would be indicated by lower inference rates amongst the ASD participants on problems with opposite conclusions. A 4 x question type (MP, MT, AC and DA) by 2 x conclusion type (standard or opposite) repeated measures Anova on inference rates, with autism as a between subjects factor, revealed a significant main effect of question type ($F(3,168) = 3.30, MSE = 0.13, p = .02, \eta^2_p = .06$) and a significant two way interaction between question type and conclusion type ($F(3,168) = 3.47, MSE = 0.14, p = .02, \eta^2_p = .06$), showing higher rates of inference for standard than opposite conclusions on the denial inferences, MT and DA. Crucially, however, the two way interaction between conclusion type and group was not significant ($F(1,56) = 1.04, MSE = 0.11, p = .31, \eta^2_p = .02$). This shows that there was no significant tendency amongst the participants with ASD to generate 'yes' responses more often than the typical participants. The three-way interaction between question type, expected response and group was also non-significant ($F(3,168) = 0.34, MSE = 0.05, p = .80, \eta^2_p = .01$).

(Put Table 4 here)

Follow up t tests revealed no significant differences between groups in inference rates for standard or opposite conclusions on any of the argument forms. For MP questions with standard conclusions ($t(56) = -0.49, p = .63$), MP questions with opposite conclusions ($t(56) = 0.72, p = .47$), MT opposite questions ($t(56) = 0.34, p = .74$), MT standard questions ($t(56) = 0.43, p = .67$), AC standard questions ($t(56) = 1.20, p = .33$), AC opposite questions ($t(56) = 1.39, p = .33$), DA opposite questions ($t(56) = -0.29, p = .77$), DA standard questions ($t(56) = 0.22, p = .83$).

Discussion

Experiment 2 shows that the adolescents with ASD do not differ from typically developing adolescents in the number of yes responses given to the reasoning problems. The pattern of findings shown in Table 4 also demonstrates that the adolescents with ASD are engaged in reasoning and do not significantly differ from the typical group in the responses given, regardless of whether the standard response is affirmative or not. The adolescents with ASD, do not, therefore, show a yes-saying response bias.

Previous studies of contrary-to-fact reasoning among children with autism present conflicting findings (Leevers & Harris, 2000; Scott, Baron-Cohen & Leslie, 1999). These differences have been explained by reference to a yes response bias (Leevers & Harris, 2000). Our materials, on the other hand, used familiar information which was in line with empirical knowledge about the world. The fact that we did not find evidence for a yes response bias suggests that the pattern of responding among children with ASD seen in previous studies may be particular to reasoning with content that is not empirically true. The tendency for children with ASD not to engage in imaginary play (see Jarrold, 2003 for a review) and to have difficulties understanding pretence (Nielsen & Dissanayake, 2001) and non-literal aspects of language (Tager-Flusberg, 2000) would also suggest that this might be the case.

The conditional reasoning data are not explained by a response bias and remain consistent with our hypothesis that the reasoning of adolescents with ASD is less likely to be contextualized with relevant background knowledge. Our group with ASD appear not to integrate available counterexamples during reasoning to the same degree as typically developing controls. There remains, however, another possible explanation for our findings. Individuals with ASD have been shown to have restricted and obsessive areas of interests (Murray, Lesser & Lawson, 2005) and to show impairment in the generation of novel thoughts and ideas (e.g. Bishop & Norbury, 2005; Turner, 1999). It may be the case that, for the participants with ASD, relevant background information is not available and they are simply

less able to generate counterexamples compared to the control group. The materials used in Experiment 1 were pretested on a group of typically developing children. It is possible that adolescents with ASD do not have access to the same number or type of counterexamples for these materials. It was necessary to conduct a third study to explore this possibility, in which the two groups were compared on their ability to generate the counterexample cases involved in the reasoning problems of Experiment 1.

Experiment 3

The purpose of Experiment 3 was to explore the possibility that a lack of contextualized reasoning among adolescents with ASD was related to an inability to generate counterexamples. The ability of typically developing adolescents and adolescents with ASD to generate disabling conditions and alternative antecedents was measured by performance on a generation task, based on that of Cummins et al. (1991).

Method

Participants

Participants for the generation task included 32 typically developing adolescents and 20 adolescents with ASD. All of the participants had previously taken part in Experiment 1. Once again no significant differences were found on measures of chronological age ($t(50) = 0.46$ $p = .65$), age corrected standard vocabulary scores ($t(50) = -1.22$ $p = .23$), inhibition ($t(50) = 2.04$ $p = .08$) or working memory ($t(50) = 0.95$ $p = .35$).

Materials and procedure

The participants were presented with a booklet containing eight conditionals, four AC and four MP statements, taken from each of the four high-low categories identified by the pretest. Participants were asked to generate as many counterexamples as possible in one and a half

minutes. All materials were read aloud by the experimenter. Participants were presented with the 8 statements in the following format:

Rule: If Marvin wears wellies, then his feet will stay dry.

Fact: Marvin's feet stay dry, but he is not wearing wellies.

Write down as many reasons as you can that could make this possible.

Results

A 2 (group) by 2 (high Vs low disablers) Anova was performed on the data for MP questions, with autism as a between subjects factor. The analysis revealed a main effect of disablers ($F(1,50) = 68.16$, $MSE = 2.34$, $p = < .001$ $\eta^2_p = .58$). The two-way interaction between disablers and autism was not found to be significant ($F(1,50) = 0.22$, $MSE = 2.34$, $p = .64$ $\eta^2_p = .004$), such that there was no significant difference in generation performance between the two groups.

An equivalent Anova was performed on the data for AC questions. The analysis revealed a main effect of alternatives ($F(1,50) = 278.82$, $MSE = 1.53$, $p = < .001$ $\eta^2_p = .85$) In line with the previous analysis of disabling conditions the two-way interaction between alternatives and autism was not found to be significant ($F(1,50) = 0.01$, $MSE = 1.53$, $p = .94$ $\eta^2_p = <.001$) showing, once again, that there was no significant difference in generation performance between the two groups.

Further analysis was carried out in order to ascertain whether the two groups were generating different types of counterexamples. The counterexamples generated were categorized into four types based on the taxonomy used by Verschueren et al. (2002). Types ranged from those which are strongly related to the content of the premises to those which represent more remote situations. Type 1 constituted 'real' counterexamples where either an alternative cause, which would lead to the same effect, is generated or an event which would

stop the effect from occurring. Type 2 referred to answers which state that there are possible exceptions, although they are not explicitly stated. Type 3 referred to answers which state that an enabler is not necessary, for example, the given cause is not necessary for the effect to occur. Type 4 included more remote answers referring to generalizations, invalid rules and intervening instances.

Multivariate analysis revealed no significant difference between autistic and typical groups in terms of overall numbers of counterexamples generated, $F(2,49) = 0.32$ $p = .73$ $\eta^2_p = .01$. Follow up Univariate Anovas revealed no significant differences between groups in terms of types of counterexamples generated. Means for each type of counterexample are shown in Table 5.

(Put Table 5 here)

A measure of the influence of counterexamples in the reasoning task across all inferences was also derived by calculating the difference between levels of endorsement where many counterexamples were available compared to cases where few counterexamples were available. This measure was correlated with total numbers of counterexamples generated excluding remote or invalid type 4 examples. Analysis revealed significant correlations between the influence of counterexamples during reasoning and numbers of counterexamples generated for the typical group $r(32) = -0.39$, $p = .03$ but not for the group with ASD $r(20) = -0.16$, $p = .49$.

Discussion

Experiment 3 demonstrated that there were no significant differences in the numbers or type of counterexamples generated between the typical group and the group with ASD. This suggests that the both groups have similar background information available for activation. These findings also show that the adolescents with ASD are able to retrieve background knowledge when instructed to do so. There is still a possibility, however, that they do not

spontaneously activate such background knowledge during reasoning. These results appear to conflict with previous studies showing an impairment in the generation of novel ideas. The fact that our participants with ASD were able to generate counterexamples may be related to the fact that they were explicitly cued to do so.

Analysis revealed significant correlations for the typical group between the influence of counterexamples during reasoning and the generation of counterexamples. For the group with ASD the ability to generate counterexamples when instructed to do so was not related to reasoning performance suggesting that either they did not tend to spontaneously generate counterexamples during reasoning or they did not integrate activated counterexample information.

General discussion

The results of Experiment 1 support the hypothesis that adolescents with ASD would be less influenced by available counterexamples in a conditional reasoning task. The adolescents with ASD did not differ from typically developing adolescents in judgments concerning the believability of the relations described in the premises. Patterns of performance in the conditional reasoning task, therefore, do not reflect differences in participants' underlying beliefs in the conditional statements. Experiment 2 explored the possibility that the conditional reasoning results reflected a yes response bias. The adolescents with ASD were not found to differ from typically developing adolescents in their willingness to give negative responses. The possibility that the reasoning performance of the group with ASD reflected differential availability of counterexamples in long term memory was ruled out by Experiment 3, which showed no differences between groups on a counterexample generation task.

The adolescents with ASD showed no significant effect of background knowledge, in the form of disabling conditions, on the valid MP inference. The same group showed a small effect of background knowledge, in the form of alternatives, on AC but significantly less

contextual influence than the typically developing group. Hence, the results strongly support our prior hypothesis that spontaneous contextualization of reasoning would be reduced in adolescents with ASD.

An important feature of our research design is that the results cannot be interpreted in terms of good and bad reasoning, from a normative viewpoint, as is known to relate generally to cognitive ability (Stanovich, 1999). MP is a valid inference, which logically should be drawn. The fact that our typically developing adolescents were strongly influenced by prior beliefs in their tendency to endorse MP is therefore technically evidence of a cognitive bias - a bias which was wholly absent in the group with ASD. However, since AC is an invalid inference, it is a logical error to endorse it. Any suppression of AC inferences due to availability of counterexamples is hence a *debiasing* effect. Examination of Figure 2 shows that for low counterexample cases endorsement rates of AC were similarly high in both groups. However, the availability of counterexamples debiased reasoning in the typical group much more strongly than in the group with ASD. So the effect of context is to decrease logical accuracy for MP but to increase logical accuracy for AC. The fact that the reasoning of the typical group was more belief-based in both cases hence shows that the difference between groups has nothing to do with logical reasoning ability as such. If we take a broader view of rationality in reasoning than that provided by logic, however, it becomes apparent that the lack of spontaneous contextualization of reasoning will be a major handicap for adolescents with ASD in everyday thinking and reasoning. As Evans and Over (1996) have pointed out, in real life (as opposed to the psychological laboratory) it is adaptive to reason from *all relevant belief*.

In general, even when instructed to do so, only those individuals with high cognitive capacity are able to reason logically, where logic and belief are in conflict (e.g. Capon, Handley & Dennis, 2003; De Neys, 2006; Klaczynski, 2000). In normal adults this requires a strong effort to inhibit prior belief. It was not the case that the group with ASD showed better developed inhibitory abilities, the Stop-Signal Task revealed no significant differences in

inhibition performance between the two groups. In the case of our participants with ASD, therefore, we do not believe that any such effort at decontextualisation was involved. Rather, we propose, that the usual contextualisation which normal reasoners struggle to suppress, does not occur with the adolescents with ASD.

Interestingly the group with ASD did not significantly differ in the responses they gave in the likelihood judgment task compared to the typical group. Automatic associative belief based processes appear to be intact. As a consequence the group with ASD was able to arrive at a degree of belief in the conditional. This suggests that individuals with ASD may be able to contextualise inputs when contextualisation relies on implicit associative processes. Such implicit processes have been shown to have a distinct influence on reasoning apart from the explicit influence of specific counterexamples. (Verschueren, et al. 2005; Weidenfield, et al. 2005).

The fact that our participants with ASD were able to generate counterexamples is in conflict with previous studies which show impaired generation of novel ideas. Individuals with ASD have shown restricted performance relative to controls in response to tasks involving word fluency (generation of as many words as possible in a given time span) (e.g. Minshew, Goldstein, Muenz & Payton, 1992), ideational fluency (generation of as many uses as possible for a given object in a set time span) (e.g. Turner, 1999) and impairment in the spontaneous use of pretence in play (Jarrold et al., 1996). There are, however, other studies which show that individuals with ASD show no impairment in similar tasks (e.g. Boucher, 1988; Minshew, Goldstein and Seigel, 1995). Boucher demonstrates that individuals with ASD have a specific problem with the spontaneous generation of novel ideas when no cues are provided. Our generation task involved very specific prompts in the form of rules and facts. Participants did not have to devise a generation strategy, they simply had to report the resulting counterexamples activated on the basis of the cues given. What is perhaps surprising, nonetheless, is that our group with ASD did not differ in terms of the types of

counterexamples generated. Turner, for example, found that individuals with autism were able to report the usual uses, cued by a given object, but were unable to derive more imaginative or out of the ordinary responses not normally associated with the use of the target. We might expect, therefore, that typical groups and groups with ASD might differ in the generation of remote or exceptional instances of counterexamples. This was found not to be the case. However, our results do show that the responses given by both groups show a marked tendency to generate 'real counterexamples' as opposed to generalisations and more remote or exceptional examples, where numbers generated by both groups were very low.

The lack of contextualization exhibited by our group with ASD may be due to the tendency not to integrate available background knowledge with presented material. If individuals with ASD have a specific problem with the spontaneous generation of novel ideas where cues are not provided, however, this suggests a further possibility. It may be that our group with ASD were able to generate counterexamples when prompted to do so but did not generate background knowledge spontaneously when engaged in online reasoning. This study cannot distinguish between these two possibilities. Recent work by Pijnacker et al. (2009) suggests, however, that individuals with autism are less influenced by contextual information in conditional reasoning even where such information is explicitly presented. The study by Pijnacker et al. would, therefore, support the claim that individuals with ASD tend not to integrate background information available to them during everyday conditional reasoning.

The adolescents with ASD did not show the kind of contextualised reasoning typically found in an adolescent population. In some ways the reasoning performance of the group with ASD had more in common with reasoning patterns found amongst younger children. Young children show less influence of background knowledge compared to adolescents (Markovits & Janveau-Brennan, 1999). Implicit probabilistic influences on reasoning are less cognitively demanding and children as young as 6 years of age are able to make probabilistic judgments about conditional statements (Markovits & Thompson, 2008). This was also found

to be the case with our adolescents with ASD. Although they were less affected by the availability of counterexample information they showed no impairment in their ability to arrive at probabilistic judgments of presented material. Where our adolescents with ASD differ from younger, typically developing children is that they show no lack of available background knowledge. They also demonstrated similar abilities to typical adolescents in retrieving counterexamples, but only when explicitly instructed to do so. As we have already stated it is possible that, like typically developing younger children, their ability to spontaneously retrieve counterexamples is under developed.

Although young children have difficulties effectively representing the relationships involved in conditional reasoning, typically developing adolescents, on the other hand, have the ability to form complex schemas and to activate and incorporate background knowledge in order to reason in context (Markovits & Barrouillet, 2002). Weak Central Coherence accounts of autism would predict that reasoners on the autistic spectrum, like younger children, would tend not to form complex representational models where it is necessary to integrate presented material with other relevant knowledge.

Our results support Frith's (1989; see also Happé & Frith, 2006) claim that individuals with autism have a tendency not to process information in context. But our work also highlights difficulties with equating global coherence across many different modalities, involving differing types of processing and levels of processing complexity. Our participants with ASD were able to use implicit associative processes to arrive at a degree of belief in the conditionals presented and were also able to generate specific examples from long term memory when asked to do so. In both of these tasks the performance of the group with ASD showed similar performance to the typical group. Our findings suggest, therefore, that children with ASD can activate background knowledge and that they can integrate implicit knowledge with presented material in order to create coherent models. What they fail to do is to show evidence of contextualized thinking in an explicit reasoning task.

Weak Central Coherence accounts of processing in context have been conceptualised across a number of widely differing cognitive and perceptual tasks and results have been conflicting (See Happé & Frith, 2006 for a review). Lopez and Leekam (2003) suggest that individuals with ASD tend not to show impairments in contextualised processing in visuo-spatial tasks including Navon tasks or visual illusions tasks (E.g. Ozonoff, Strayer, McMahon, & Filloux, 1994; Ropar & Mitchell, 1999) but do demonstrate difficulties processing complex verbal information in context (e.g. Frith & Snowling, 1983; Jolliffe & Baron-Cohen, 1999). Our work would suggest, however, that it is not the verbal nature of these tasks that leads to information processing difficulties for groups with ASD but the fact that they involve effortful integration of explicit material with given stimuli. Both our likelihood judgment task and the conditional reasoning task were verbal in nature and used materials with the same content.

In some ways our findings may be more in line with Minshew's Complex Processing Deficit account of autism (Minshew et al., 1997; Williams, Goldstein & Minshew, 2006) which proposes that individuals with ASD have a general impairment in processing complex information. A difficulty in drawing information together in order to create concepts and schemas means that incoming information cannot be processed with the support of a contextual framework. This impairment is only apparent in tasks which draw on limited cognitive resources. Less complex tasks or those which generally make fewer demands on cognitive resources will be unimpaired. Certainly this account would explain why the conditional reasoning task, which has been shown to be related to cognitive ability (Verschueren et al. 2004), would present difficulties for the group with ASD whilst the likelihood task would not. It is important to note, however, that our groups did not significantly differ on measures of Working Memory and Minshew is not claiming that individuals with ASD have a problem with cognitive capacity per se.

The findings presented here raise some interesting questions. It is important to stress, however, that standardised diagnostic measures such as the Autism Diagnostic Observation Schedule-Generic (ADOS-G) (Lord, Risi, Lambrecht et al., 2000) or the Autism Diagnostic Interview-Revised (ADI-R) (Lord, Rutter & LeCouteur, 1994) were not employed in this study. While the participants with ASD were rigorously diagnosed, standard measures typically used in autism research allow for confidence in generalising across studies. Further investigation is, therefore, of particular necessity where our findings are counter to previous work. The fact that we did not find a yes response bias amongst the adolescents with ASD, for example, contradicts previous studies (Leevers and Harris 2000). The fact that the questions we used were very similar to those used in the Leevers and Harris study but differed in that they had familiar rather than contrary-to-fact content suggests that children with ASD may have specific difficulties reasoning with empirically false material. There is comparable evidence that individuals with ASD exhibit poor performance on counterfactual reasoning tasks involving reasoning about alternative possibilities not reflected in reality (Grant, Riggs & Boucher, 2004; Peterson & Bowler, 2000). Future work might investigate reasoning in populations with ASD with contrary-to-fact, counterfactual and empirically true content across childhood and adolescence.

Acknowledgement

The authors would like to thank all the schools which participated in the study: Ridgeway School, Plymstock School, Tamarside Community College, Tavistock College and Callington Community College.

Appendix

Conditionals used in the reasoning task

Low alternatives and low disablers

If butter is heated, then it will melt

If iron touches a magnet, then it will stick to it

If water is frozen, then it will become ice

If Robert cuts his finger, then it will bleed

High alternatives and high disablers

If the brake is pressed, then the car will slow down

If the window is opened, then the room will become cool

If a stone is kicked, then it will move

If a mug is dropped, then it will break

High disablers and low alternatives

If the ignition key is turned, then the car will start

If the trigger is pulled, then the gun will fire

If the correct switch is flicked, then the porch light will go on

If the doorbell is pushed, then it will ring

High alternatives and low disablers

If the apple is ripe, then it will fall off the tree

If Camilla eats an ice-lolly, then her mouth will get cold

If a towel is dropped in the bath, then it will get wet

If a balloon is pricked, then it will burst

References

- American Psychiatric Association (1994) *Diagnostic and Statistical Manual of Mental Disorders*, 4th Edition. Washington D.C.: A.P.A.
- Bishop, D. V. M., & Norbury, C. F. (2005). Executive functions in children with communication impairments in relation to autistic symptomatology 2: Response inhibition. *Autism, 9*, 29–43
- Boucher, J. (1988). Word fluency in high-functioning autistic children. *Journal of Autism and Developmental Disorders, 18*, 637–645.
- Capon, A., Handley, S. J., & Dennis, I. (2003). Working memory and reasoning: An individual differences perspective. *Thinking & Reasoning, 9*, 203 – 244.
- Colom, R., Rebollo, I., Palacios, A., Juan-Espinosaa, M., & Kyllonenb, P. C. (2004). Working memory is (almost) perfectly predicted by g. *Intelligence, 32*, 277–296.
- Cummins, D. D., Lubart, T., Alksnis, O., & Rist, R. (1991). Conditional reasoning and causation. *Memory and Cognition, 19*, 274-282.
- Cummins, D. D. (1995). Naive theories and causal deduction. *Memory and Cognition, 23*, 646-658.
- De Neys, W. (2006). Dual processing in reasoning – Two systems but one reasoner. *Psychological Science, 17*, 428 – 433.
- De Neys, W., Schaeken, W., & d'Ydewalle, G. (2005). Working memory and everyday conditional reasoning: Retrieval and inhibition of stored counterexamples. *Thinking and Reasoning, 11*, 349-381.
- Dias, M. G., & Harris, P. L. (1988). The effect of make-believe play on deductive reasoning. *British Journal of Developmental Psychology, 6*, 207-221.
- Evans, J. St. B. T. (1989). *Bias in human reasoning: causes and consequences*. Brighton:

Erlbaum.

- Evans, J. St. B. T. (2003). In two minds: dual-process accounts of reasoning. *Trends in Cognitive Sciences*, 7, 454–459.
- Evans, J. St. B. T. (2007). *Hypothetical thinking: Dual process in reasoning and judgment*. Hove, UK: Psychology Press.
- Evans, J. St. B. T. (2008) Dual processing accounts of reasoning, judgment and social cognition *Annual Review of Psychology*, 5, 255–278.
- Evans, J. St. B. T. & Over, D. E. (1996). *Rationality and reasoning*. Hove: Psychology Press.
- Evans, J. S. B. T., & Over, D. E. (2004). *If*. Oxford: Oxford University Press.
- Frith, U., (1989). *Autism: explaining the Enigma*. Oxford, UK: Blackwell Publishing.
- Frith, U. (2003). *Autism: Explaining the enigma* (2nd ed.). Oxford, UK: Blackwell Publishing.
- 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.
- Happé, F.G.E. and Booth, R.D.L. (2008) The power of the positive: Revisiting weak coherence in autism spectrum disorders. *The Quarterly Journal of Experimental Psychology*, 6, 50-63
- Happé, F. and Frith, U. (2006) The Weak Coherence Account: Detail-focused Cognitive Style in Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*, 36, 5-25
- Janveau-Brennan, G., & Markovits, H. (1999). The development of reasoning with causal conditionals. *Developmental Psychology*, 35, 904-911.
- Jarrold, C. (2003). A review of research into pretend play in autism. *Autism*, 7, 379-390.
- Jarrold, C., Boucher, J., & Smith, P.K. (1996) generativity defects in pretend play in autism. *British Journal of Developmental Psychology*, 14, 275-300

- Jolliffe, T., & Baron-Cohen, S. (1999a). 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. (1999b). The strange stories test: A replication with high-functioning adults with autism or Asperger syndrome. *Journal of Autism and Developmental Disorders*, *29*, 395–406.
- Klaczynski, P. A. (2000). Motivated scientific reasoning biases, epistemological beliefs, and theory polarization: A two-process approach to adolescent cognition. *Child Development*, *71*, 1347 – 1366.
- Klaczynski, P. A., Schuneman, M. J., & Daniel, D. B. (2004). Theories of conditional reasoning: A developmental examination of competing hypotheses. *Developmental Psychology*, *40*, 559–571.
- Leevers, H. J. & Harris, P. L. (2000) Counterfactual Syllogistic Reasoning in Normal 4-Year-Olds, Children with Learning Disabilities, and children with Autism. *Journal of Experimental Child Psychology*, *76*, 64-87.
- Logan, G.D., Schachar, R., & Tannock, R., (1997). Impulsivity and inhibitory control. *Psychological Science* *8*, 60–64.
- Lopez, B., & Leekam, S. R. (2003). Do children with autism fail to process information in context? *Journal of Child Psychology & Psychiatry*, *44*, 285–300.
- Lord, C., Risi, S., Lambrecht, L., Cook, E. H., Leventhal, B.L., DiLavore, P. C., et al. (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*, 659–85.

- Markovits, H., & Barrouillet, P. (2002). The development of conditional reasoning: A mental model account. *Developmental Review, 22*, 5-36.
- Markovits, H., & Barrouillet, P. (2004). Introduction: Why is understanding the development of reasoning important? *Thinking and Reasoning, 10*, 113-121.
- Markovits, H., Fleury, M.-L., Quinn, S., & Venet, M. (1998). The development of conditional reasoning and the structure of semantic memory. *Child Development, 69*, 742-755.
- Markovits, H., & Janveau-Brennan, G. (1999). The development of reasoning with causal conditionals. *Developmental Psychology, 35*, 904-911.
- Markovits, H., & Potvin, F. (2001). Suppression of valid inferences and knowledge structures: The curious effect of producing alternative antecedents on reasoning with causal conditionals. *Memory and Cognition, 29*, 736-744
- Markovits, H., & Thompson, V. (2008). Different developmental patterns of simple deductive and probabilistic inferential reasoning. *Memory and Cognition, 36*, 1066-1078.
- 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., Goldstein, G., Muenz, L. R., & Payton, J. (1992). Neuropsychological functioning in nonmentally retarded autistic individuals. *Journal of Clinical and Experimental Neuropsychology, 14*, 749-761.
- Morsanyi, K., & Handley, S. J. (2008). How smart do you need to be to get it wrong? The Role of cognitive capacity in the development of heuristic-based judgment. *Journal of Experimental Child Psychology, 99*, 18-36.
- Muller, U., Overton, W. F., & Reene, K. (2001). Development of conditional reasoning: A longitudinal study. *Journal of Cognition and Development, 2*, 27-49.
- Murray, D., Lesser, M., Lawson, W. (2005) Attention, monotropism and the diagnostic criteria for autism. *Autism, 9*, 139-156.

- Nielsen, M., & Dissanayake, C. (2001). A study of pretend play and false belief in pre-school children: is all pretence metarepresentational? In S. Reifel (Ed.), *Play and culture studies* (pp. 199-216). London: JAI Press.
- Ozonoff, S., Strayer, D.L., McMahon, W.M., & Filloux, F. (1994). Executive function abilities in autism and Tourette's syndrome: An information processing approach. *Journal of Child Psychology and Psychiatry*, *35*, 1015–1032.
- Peterson D.M., Bowler D.M. (2000). Counterfactual reasoning and false belief understanding in children with autism, children with severe learning difficulties, and children with typical development, *Autism*, *4*, 391–405.
- Pijnacker, J., Geurts, B., van Lambalgen, M., Kan, C. C., Buitelaar, J. K., & Hagoort, P. (2009). Defeasible reasoning in high-functioning adults with autism: Evidence for impaired exception-handling. *Neuropsychologia*, *47*, 644-651.
- 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: Perspectives from theory and research*. (pp.149–169). New Jersey: Lawrence Erlbaum.
- 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. *The Journal of Child Psychology and Psychiatry*, *39*, 765-775.
- Quinn, S., & Markovits, H. (1998). Conditional reasoning, causality, and the structure of semantic memory: Strength of association as a predictive factor for content effects. *Cognition*, *68*, B93-101.
- 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.
- Scott, F. J., Baron-Cohen, S. & Leslie, A. (1999) 'If pigs could fly': A test of

- counterfactual reasoning and pretence in children with autism. *British Journal of Developmental Psychology*, 17, 349-362.
- Shah, A., & Frith, U. (1993). Why do autistic individuals show superior performance on the Block Design task? *Journal of Child Psychology and Psychiatry*, 34, 1351-1364.
- Tager-Flusberg, H. (2000). Language and understanding minds: Connections in autism. In S. Baron-Cohen, H. Tager-Flusberg, & D. Cohen (Eds.), *Understanding other minds: Perspectives from developmental cognitive neuroscience* (pp. 124-149). New York: Oxford University Press.
- Thompson, V. A. (1994). Interpretational factors in conditional reasoning. *Memory & Cognition*, 22(6), 742-758.
- 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.
- Verschueren, N., Schaeken, W., & d'Ydewalle, G. (2005). Everyday conditional reasoning: A working memory-dependent tradeoff between counterexample and likelihood use. *Memory and Cognition*, 33, 107-119.
- Verschueren, N., Schaeken, W., & d'Ydewalle, G. (2004). Everyday conditional reasoning with working memory preload. In *Proceedings of the Twenty-Sixth Annual Meeting of the Cognitive Science Society* (pp. 1399-1404). Mahwah, NJ: Erlbaum.
- Verschueren, N., Schaeken, W. & d'Ydewalle, G. (2005). Everyday conditional reasoning: a working memory-dependent tradeoff between counterexample and likelihood use. *Memory and Cognition*, 33, 107-19.
- Wechsler, D. (1991). *Wechsler Intelligence Scale for Children* (3rd ed.). New York: Psychological Corporation. Woodcock, R.W. & Johnson, M.B. (1989, 1990).
- Weidenfeld, A., Oberauer, K., & Hornig, R. (2005). Causal and noncausal conditionals:

An integrated model of interpretation and reasoning. *The Quarterly Journal of Experimental Psychology* 58A, 1479–1513.

Williams, D. L., Goldstein, G. & Minshew, N. J. (2006). The profile of memory function in children with autism. *Neuropsychology* 20, 21-29.

Wilson, M. Bettger, J. G. Niculae, I and. Klima, E.S. (1997) Modality of Language Shapes Working Memory: Evidence From Digit Span and Spatial Span in ASL Signers. *Journal of Deaf Studies. Deaf Education*, 2, 150-160.

World Health Organization. (1993). International classification of diseases (10th ed.). Geneva, Switzerland:

Zelazo, P.D., Jaques, S., Burack J,A., & Frye D. (2002) The Relation between Theory of Mind and Rule Use: Evidence from Persons with Autism-Spectrum Disorders. *Infant and Child Development*, 11, 171-195.

Table 1. Measures of participant characteristics for autistic and typical groups

	Autistic			Typical			Differences between groups
	Range	Mean	SD	Range	Mean	SD	<i>p</i>
Chronological Age (Months)	133-203	168.08	19.43	143-188	163.61	14.90	.29
Standardised Vocabulary scores	4-13	8.65	2.98	4-16	9.42	2.96	.31
Working Memory Span	0.5-4.5	2.19	1.13	0.5-4.0	2.08	0.91	.66
Inhibition	6-62	38.55	13.03	10-57	41.21	10.28	.42

Table 2. Mean numbers of alternative antecedents and disabling conditions generated for each high-low category.

High - low categories	Mean counterexamples generated	
	Alternatives	Disablers
Low alternatives – low disablers	0.30	0.55
Low alternatives – high disablers	0.55	2.15
High alternatives – low disablers	2.73	0.98
High alternatives – high disablers	2.35	2.35

Table 3. Measures of participant characteristics for autistic and typical groups

	Autistic		Typical			Differences between groups	
	Range	Mean	SD	Range	Mean	SD	<i>P</i>
Chronological Age (Months)	141-195	166.45	15.79	137-194	163.29	16.90	.49
Standardised Vocabulary scores	4-11	6.50	2.14	4-13	7.37	1.96	.13
Working Memory Span	1.0-5.0	3.15	1.03	1.0-5.0	3.66	1.06	.09

Table 4. Mean number of inferences drawn for standard and opposite conclusions for each argument from comparing the typical group and the group with ASD

Inference	Response type	ASD	Typical
MP	Standard	1.85	1.89
	Opposite	2.00	1.97
MT	Standard	1.85	1.89
	Opposite	1.75	1.79
AC	Standard	1.90	1.97
	Opposite	1.90	2.00
DA	Standard	1.90	1.92
	Opposite	1.75	1.71

Table 5. Mean number of counterexamples generated for each type by autistic and typical groups.

Type generated	Autistic		Typical	
	Mean	SD	Mean	SD
Real counterexamples	12.10	4.89	11.75	3.16
Possible exceptions	0.15	0.67	0.13	0.34
Missing enablers	2.15	1.81	2.34	1.29
Remote counterexamples	0.40	0.68	0.72	0.99

Figure Captions

Figure 1. Mean number of endorsement responses as a percentage, given for MP questions with low and high available disablers by the autistic and typical groups.

Figure 2. Mean number of endorsement responses as a percentage, given for AC questions with high and low available alternatives by autistic and typical groups.

Fig 1

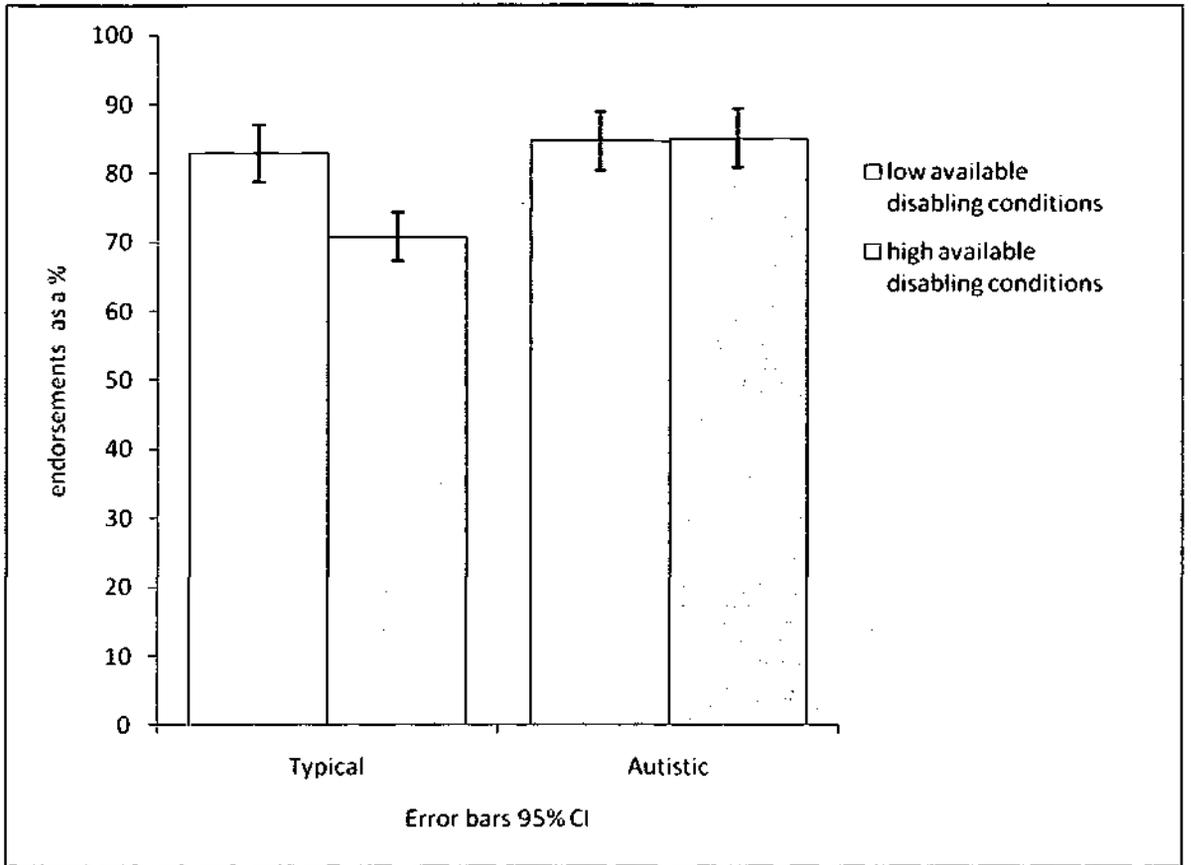


Fig 2

