Links between theory of mind and executive function in young children with autism: clues to developmental primacy

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Abstract

There has been much theoretical discussion of a functional link between theory of mind (ToM) and executive function (EF) in autism. This study sought to establish the relationship between ToM and EF in young children with autism (M = 5 years 6 months) and to examine issues of developmental primacy. Thirty children with autism and 40 typically developing children, matched on age and ability, were assessed on a battery of tasks measuring ToM (1^{st}- and 2^{nd}-order false-belief) and components of EF (planning, set-shifting, inhibition). A significant correlation emerged between ToM and EF variables in the autism group, independent of age and ability, while ToM and higher-order planning ability remained significantly related in the comparison group. Examination of the pattern of ToM-EF impairments in the autism group revealed dissociations in one direction only: impaired ToM with intact EF. These findings support the view that EF may be one important factor in the advancement of ToM understanding in autism. The theoretical implications of these findings are discussed.

Keywords: autism, theory of mind, executive function, cognitive development

Word count: 165 words

Autism is a complex neurodevelopmental disorder, whose primary features include profound difficulties in reciprocal social interaction, abnormalities in verbal and nonverbal communication, and a limited behavioral repertoire consisting of stereotyped, repetitive activities. Theory of mind (ToM) – the specific ability to attribute mental states to oneself and to others (Baron-Cohen, Leslie, & Frith, 1985) – and executive function (EF) – a term describing a set of functions thought to be necessary for flexible, future-oriented behavior, especially in novel circumstances (Pennington & Ozonoff, 1996) – have each been hypothesized to play a causal role in the development of these behavioral features. It is now well-established that individuals with autism show marked impairments (relative to mental age and to various comparison groups) on tasks tapping ToM <u>and</u> EF (see Baron-Cohen, Tager-Flusberg, & Cohen, 2000, and Hill, 2004, for reviews). Consequently, one major task for researchers has been to explain the coexistence of impairments in both cognitive domains. Indeed, there has been much theoretical debate surrounding the precise nature of the relationship between ToM and EF in autism (Moses & Carlson, 2004; Ozonoff, Pennington, & Rogers, 1991; Perner, 1998, 2000; Perner & Lang, 1999, 2000; Russell, 1996, 1997; Zelazo, Jacques, Burack, & Frye, 2002).

This paper presents an empirical investigation that aimed to establish the putative link between ToM and EF in young children with autism and typically developing children and further, to elucidate issues of developmental primacy by examining the pattern of ToM-EF impairments in autism. Before describing the study, however, the paper begins with a brief outline of the evidence for the ToM-EF link in typical development, followed by an overview of the various theoretical models that purport to explain this link. Attention is also directed towards the few empirical studies that have assessed the link between ToM and EF in individuals with autism.

ToM and EF in typical development

In typically developing children, both ToM and EF undergo considerable development over the preschool years. One of the hallmarks of a child's developing ToM is an understanding of beliefs, which often involves (mistaken) representations of reality. At around the age of four, typically developing children have a tendency to succeed on the classic false-belief task which requires the understanding that a protagonist will search for an object in a location where he/she falsely believes it to be rather than where the child herself knows it to be (Wimmer & Perner, 1983). At around the same time, preschoolers are already showing considerable mastery of executive control (Carlson, 2005; Diamond, 2002; Hughes, 1998a; Luciana & Nelson, 1998; Zelazo & Müller, 2002). They begin, that is, to succeed on tasks requiring the retention of information in working memory and the inhibition of a prepotent response – two essential features of executive tasks (Pennington et al., 1997).

Advancements in ToM have been shown to be intimately tied to improvements in EF in normative development. Russell, Mauthner, Sharpe, and Tidswell (1991) first demonstrated significant associations between success on a test of false-belief and performance on the 'windows task', a deception task that could be construed as a measure of EF. There have since been numerous reports of robust associations between individual differences in ToM (typically, false-belief prediction tasks) and individual differences in EF independent of age and IQ, in typically developing preschoolers (Carlson, Mandell, & Williams, 2004; Carlson & Moses, 2001; Carlson, Moses, & Breton, 2002; Carlson, Moses, & Claxton, 2004; Frye, Zelazo, & Palfai, 1995; Hughes, 1998a, b). A meta-analysis reported that the average effect size of these studies was quite high (Cohen's d = 1.08; Perner & Lang, 1999). Moreover, false-belief understanding has been related to specific executive skills, including attentional flexibility (Frye et al., 1995; Hughes, 1998a), inhibitory control (Carlson et al., 2002, 2004; Hughes, 1998a), and working memory (Davis & Pratt, 1996; Keenan, 1998; Keenan, Olson, & Marini, 1998), but not planning ability (Carlson et al., 2004).

The simplest explanation offered for the link between ToM and EF in early development has been that tasks tapping ToM impose an executive requirement; hence, on this view, executive control is held to play an important role in the expression of ToM (Carlson & Moses, 2001; Leslie, 1994; Leslie & Polizzi, 1998; Moses, 2001; Russell et al., 1991). On the false-belief task, the correct prediction of the protagonist's action relies on the child suppressing their own prepotent (though incorrect) knowledge of current reality while simultaneously holding in mind information about the protagonists' actions and the whereabouts of the object in question. Manipulating the executive demands of the false-belief task (for example, by reducing the prepotency of current reality) affects the performance of young typically developing children (Carlson, Moses, & Hix., 1998; Cassidy, 1998; Hala & Russell, 2001; Leslie & Polizzi, 1998).

At least two pieces of evidence, however, indicate that the ToM-EF relationship might not be as straightforward as the expression account claims. First, significant associations have been reported between executive measures and ToM tasks which make minimal executive demands in typically developing preschoolers (Hughes, 1998a; Moses & Carlson, 2004; Perner, Lang, & Kloo, 2002). Second, children with autism have been found to pass a false-photograph task, a non-mental analogue of the false-belief task carrying similar executive requirements (Leekam & Perner, 1991; Leslie & Thaiss, 1992; but see Russell, Saltmarsh, & Hill, 1999 and Sabbagh, Moses, & Shiverick, 2006, for evidence challenging this view). The fact that false-belief tasks cannot be construed entirely as executive tasks has prompted the need to specify further the association between ToM and EF.

Theoretical positions for the link between ToM and EF

This impetus has led to several, more controversial proposals related to the emergence of ToM/executive abilities. Two prominent theories, Perner's metarepresentational account and Russell's executive account, both share the idea of functional dependency between ToM and EF. Crucially, the theories diverge with respect to the predictions concerning the causal direction of the ToM-EF relationship in typical development and in autism.

Perner and colleagues (1998, 2000, Perner & Lang, 1999, 2000; Perner, Stummer, & Lang, 1999) propose that metarepresentational capacity underlying ToM is a prerequisite for the development of executive control (see also Carruthers, 1996). For Perner, the key conceptual change for children at about 4 years of age is an explicit understanding of representations as representations, i.e., 'metarepresentation'. This affords the child with the insight that propositions can be evaluated differently by different people, and importantly, that propositions or representations take causal precedence over reality. Perner argues that it is this understanding – the idea that behavior is causally mediated by internal states – that is critical to the development of executive control.

Perner considers executive control to be 'meta-intentional', and asserts that representations of intended action sequences must be represented as intended. Consequently, the initiation of novel action sequences through planning involves access to declarative (i.e., explicit) representations of one's desires or goals. Metarepresentation is particularly important on tasks of what Perner calls 'executive inhibition', where a new action sequence must be executed in place of an existing (though maladaptive) action sequence. Such tasks require conceptualizing action sequences as representations ('representational vehicles') that have causal power. For example, on a task of inhibitory control, Luria's hand-game, the child must recognize that the tendency to imitate the experimenter’s hand movement (e.g., make a fist) is maladaptive, and that in order to succeed on the task, he/she must explicitly inhibit this tendency and initiate the opposite movement (e.g., point a finger). Thus, Perner’s central claim is that the ability to engage in flexible, goal-directed behavior is only attained when the child has developed a representational understanding of mind. Accordingly, deficits in executive control in autism may be the result of a primary impairment in metarepresentation.

Russell (1996, 1997) presents a directly opposing view: that EF is a prerequisite for ToM (see also Pacherie, 1997). Russell proposes that the experience of agency (which entails the abilities to monitor one’s actions and to act with volition) is fundamental for acquiring insight into the intentional nature of action. This rudimentary (‘pretheoretical’) form of self-awareness, which does not rely upon an understanding of concepts (i.e., it is not representational – unlike Perner’s view), is a necessary precondition for understanding mental states. For Russell, the ability to monitor one’s own actions (particularly involving the monitoring of high-level intentions) is central to all executive tasks, and is considered to be the primary impairment in autism. Deficits in self-monitoring in turn lead to a failure to develop an understanding of mental concepts.

In more recent work, Russell (2002) has revised his theory in light of counterevidence from his own laboratory, which has challenged the notion that impairments in action-monitoring are specific to autism (Hill & Russell, 2002; Russell & Hill, 2001). Considering the well-established impairment in cognitive flexibility in autism, Russell has suggested that poor mentalizing abilities might be the result of an inability to hold in mind and shift between arbitrary rules or cognitive domains. The original thread of his argument still stands, though, and he continues to contend that executive control is crucial for the development of an understanding of other minds.

A few studies have examined the causal direction of the ToM-EF relationship in typical development. Hughes (1998b) found that performance on tests of EF (specifically inhibitory control) at age 4 predicted performance on ToM measures one year later, but not the other way around[1], and Carlson et al. (2004) reported that this relationship persisted in a group of much younger children (aged 24 months) independent of age, sex, and verbal intelligence. Using a microgenetic approach, Flynn, O'Malley and Wood (2004) assessed 3 ½-year-old children every four weeks for six months on tasks tapping inhibitory control and false-belief understanding. They found that preschoolers' successful performance on tasks of inhibitory control developmentally preceded their success on false-belief tasks. These three longitudinal studies provide evidence of an asymmetric relationship between EF and ToM, a pattern that is in favor of Russell's executive account. Results from a training study by Kloo and Perner (2003), however, are not so supportive. They reported that training on the Dimensional Change Card Sort task (DCCS; a measure of cognitive flexibility) enhanced children's false-belief performance, and vice versa. This finding supports the notion of a functional link between ToM and EF, but provides little insight into the developmental underpinnings of this link. Notably, however, training in false-belief understanding failed to improve children's post-training false-belief performance, rendering the findings from this study somewhat difficult to interpret.

A recent cross-cultural study examined the relationship between ToM and executive control in age- and verbal mental age-matched U.S. and Chinese preschoolers (Sabbagh, Xu, Carlson, Moses, & Lee, 2006). These authors found that individual differences in ToM were significantly related to individual differences in EF across children from Chinese and U.S. cultures. Group analyses showed, however, that while young Chinese children showed proficient executive control, they had not yet mastered false-belief prediction. This latter result is consistent with an emergence account like

Russell's, as it acknowledges that poor performance on ToM tasks could occur in combination with good performance on EF tasks. (Note that one must invoke the caveat that functioning in one domain is necessary but not sufficient for the development of functioning in the other domain.)

ToM and EF in autism

Perner's and Russell's theories generate explicit (yet opposing) predictions about the precise nature of the developmental relationship between ToM and executive control in atypical development. Impairments in ToM and EF have been frequently associated with the autism phenotype, and deficits in both domains are considered to be causally implicated in the development of the disorder. Evidence from autism, therefore, should assist in the evaluation of these competing positions and may provide some clues to the developmental primacy of ToM and EF. As with typical development, however, there has been surprisingly little attention devoted to the nature of the relationship between ToM and EF in individuals with autism.

Ozonoff et al. (1991) tested high-functioning children and adolescents with autism (M age = 12 years) and comparison children, individually matched for chronological age, verbal ability, and gender, on a battery of ToM (including first- and second-order false-belief) and executive (comprising planning and cognitive flexibility) tasks. As expected, children with autism performed significantly worse on ToM and EF measures relative to comparison children. A significant correlation also emerged in the autism group between the EF and ToM composite scores, independent of intellectual functioning, though this same correlation did not persist in the comparison group. In order to examine the pattern of 'impairments' in each domain, Ozonoff et al. calculated the proportion of individuals with autism who performed below the mean composite score of the comparison group for ToM and EF. Remarkably, they found that 'impairments' in EF were almost universal in the autism group (96%), whereas only half the group (52%) displayed concomitant deficits in first-order ToM[2]. Ozonoff et al. concluded that executive deficits were primary in autism, though not causally related to ToM impairments, as the two deficits did not always co-occur. Instead, they proposed a new account of the ToM-EF link: that the two deficits were correlated in autism by virtue of their neuroanatomic proximity, specifically in prefrontal cortical regions (see Duncan & Owen, 2000, and Frith & Frith, 2003, for reviews on the neural substrates of EF and ToM, respectively).

These authors' dismissal of the notion of functional dependency between ToM and EF, however, may have been a little premature. Ozonoff et al. did not calculate the proportion of individuals with autism who displayed intact ToM with impaired executive control. Perner et al. (2002) highlighted the possibility that there should have been at least some children with this pattern of impairment in Ozonoff et al.'s sample, which would in fact be in support of Perner's metarepresentational account.

Following Ozonoff et al., three additional studies have also reported significant correlations between ToM and aspects of executive control. Joseph and Tager-Flusberg (2004) reported significant associations between ToM scores and scores on a task assessing both working memory and inhibitory control (the Knock-Tap task) in school-aged children with autism spectrum disorder (ASD; M age = 9 years), independent of the effects of verbal ability and nonverbal ability. Zelazo et al. (2002) demonstrated links between ToM and another executive skill: cognitive flexibility. They found that performance on a card-sorting task (the DCCS task) was significantly related to false-belief performance in a small group (n = 10) of mildly-impaired children with autism (M age = 10 years), although they failed to partial out the effects of age and general ability. Colvert, Custance, and Swettenham (2001, cited in Colvert, Custance & Swettenham, 2002) replicated Zelazo et al.'s study, confirming the robust correlation between false-belief understanding and set-shifting in the autism group, even once general and developmental differences were taken into account. Zelazo et al. attributed the link between ToM and set-shifting deficits in autism as evidence for their Cognitive Complexity and Control (CCC) theory: a fourth account of the ToM-EF relation. They argued that (mildly-impaired) children with autism fail both sorts of tasks because these tasks required children to use embedded, hierarchical (‘if-if-then’) rules of comparable complexity. Importantly, Zelazo et al. make no claims concerning the developmental primacy of either ToM or EF; developments in both abilities are underpinned by the capacity to reason using complex rule structures.

It is clear from this handful of studies that ToM and EF are related in autism. Several methodological limitations in the studies, however, make it difficult to discern the precise relationship between ToM and components of EF. First, two of these studies (Joseph & Tager-Flusberg, 2004; Zelazo et al., 2002) did not include a comparison group, making it uncertain whether children’s performance on EF and ToM measures was consistent with their age and ability. Second, while it has been established that ToM skills are associated with a variety of executive skills (cognitive flexibility; Colvert et al., 2002; Zelazo et al., 2002; working memory/inhibition: Joseph & Tager-Flusberg, 2004), it is not clear which executive skills are most strongly associated with ToM development in autism, or whether these executive skills are the same ones that have been implicated in the typically developing literature. Third, examination of the pattern of ToM-EF deficits in autism (as per Ozonoff et al.) has the potential to be a very useful approach to understanding the nature of the link between these domains. In Ozonoff et al.’s study, an ‘impairment’ in the autism group was defined in relation to performance of the comparison group, such that they calculated the proportion of individuals with autism scoring more poorly than the mean score of the comparison group. This definition of ‘impairment’, however, might have been a little misleading; indeed, if performance on the tasks was normally distributed, then one should expect to find half of the comparison group to also show ‘impairments' in ToM and EF. One important question, then, is whether a similar pattern of findings arises when a more conservative criterion is used (one standard deviation below the mean of the comparison group; Lezak, 1995). Finally, all of the abovementioned studies on autism have focused upon the ToM-EF link in either school-aged children or adolescents. It remains to be seen, therefore, whether the ontogenetic relationship between ToM and EF holds in young children with autism.

The present study was designed to address these concerns. The overarching goal was to delineate the nature of the relationship between ToM and EF in relatively large samples of young children with autism and typically developing children, matched on chronological age, verbal ability, and nonverbal ability. False-belief understanding (first- and second-order false-belief) was used to index ToM, and several measures of EF were included to assess particular executive skills: the Mazes task assessed simple planning skills; the Tower of London tapped higher-order planning ability; Luria’s hand-game assessed inhibitory control and working memory; and a Set-shifting task measured cognitive flexibility. All tasks were developmentally appropriate and have been used previously with typically developing preschool children (e.g., Hughes, 1998a) and children with autism (e.g., Liss et al., 2001).

This study had two primary aims. The first of these was to explore the relationship between ToM and components of EF in autism and in typical development. Correlational analyses were used to examine whether individual differences in scores on ToM tasks would be related to individual differences in scores on various EF tasks. Based on prior findings and the theoretical proposals reviewed herein, it was anticipated that scores on executive tasks would be significantly related to scores on ToM measures in autism and typically developing groups, independent of the potentially confounding effects of chronological age, verbal ability, and nonverbal ability. One key objective was to determine which components of EF were related specifically to false-belief understanding. Inhibition/working memory and set-shifting have been linked to false-belief prediction in typically developing preschoolers, yet links between ToM and specific executive skills have been less apparent in autism. Both emergence theories make similar predictions regarding which executive skill should be most strongly related to false-belief prediction; Perner has suggested that tasks of 'executive inhibition' should be related specifically to ToM, while Russell has indicated that false-belief understanding should be correlated with scores on tasks that involve holding in mind, and switching between, arbitrary rules. According to both accounts, then, false-belief scores should be significantly correlated with scores on Luria's hand-game, the Tower of London task, and the Set-shifting task, but not the Mazes task (as performance on this task did not involve 'executive inhibition' or the rehearsal of an arbitrary rule).

The second aim was to examine the pattern of ToM-EF impairments (including dissociations, if any) in the group of children with autism, similar to Ozonoff et al. Perner and Lang (1999, 2000) highlighted the potential significance of examining dissociations between ToM and EF in both typical and atypical populations. Perner contends that good ToM is a prerequisite for the development of good EF, while Russell holds the opposing view, that good EF is a prerequisite for the development of good ToM. Neither Perner nor Russell makes the stronger claim that adequate functioning in one domain is necessary and sufficient for the development of functioning in the other domain. They do, however, argue that functioning in one domain is especially important for the development of functioning in the other domain. This results in a diverging set of predictions concerning the pattern of dissociations between ToM and EF (see Table 1). Perner does not allow for the possibility that poor ToM could occur in the face of intact EF, as he argues that an impairment in the capacity for metarepresentation should lead to impaired executive skills. Importantly, however, the reverse dissociation – intact

ToM with impaired EF – is compatible with Perner's account, as although good ToM is important for the development of good EF, it is not sufficient for its development alone.

Conversely, Russell's theory does not permit the possibility of impaired EF coupled with intact ToM, as he argues that poor self control should lead to an inability to understand our own and others' minds. His account, however, does acknowledge that intact EF might occur alongside impaired ToM, as he allows for the possibility that impairments in ToM could occur for reasons other than impaired executive control. For Russell, language is afforded an important role in the development of self-control, and it is implicit in Russell's writings that language (or more specifically, the capacity for inner speech) might be one additional condition for the development of ToM.

Insert Table 1 about here

In an attempt to tease apart these competing hypotheses, children with autism were grouped according to whether they displayed impairments on ToM and/or EF tasks. Notably, a conservative definition of 'impairment' was employed in the present study: the percentage of children with autism who scored more than one SD below the mean of the typically developing group.

Method

Participants

Descriptive information is provided in Table 2. A total of 80 children aged between 4 and 7 years were recruited for a larger study on cognitive abilities and disabilities in autism. The majority of children were White. Eight additional children (5 children with autism, 3 typically developing children) were also recruited but failed control questions on the ToM tasks (see below) and so were excluded from the study. Children with either a medical diagnosis (e.g., epilepsy), a neurodevelopmental diagnosis other than autism (e.g., ADHD), a full-scale intelligence score below 80, or who were in receipt of medication, were not included in this study.

Forty children with autism spectrum disorder (ASD) (35 boys) were identified through early intervention agencies, parental support groups, speech therapists, and pediatricians. A more homogenous group was formed for the present study by including only those children who had a clinical diagnosis of Autistic Disorder (n = 30), according to DSM-IV criteria (American Psychiatric Association, 1994). These children did not differ significantly in age, verbal ability, or nonverbal ability, from the children (n = 10) diagnosed with Pervasive Developmental Disorder – Not Otherwise Specified that were excluded from the study (ps ranged between .41 and .66). The clinical diagnosis of the 30 remaining children (25 boys) was confirmed independently using the Autism Diagnostic Interview – Revised (ADI-R; Lord et al., 1994), a semi-structured interview with caregivers for the differential diagnosis of autism and related disorders; children either met full criteria (n = 25) or scored one point below the diagnostic cut-off for autism (n = 5) (see Table 2 for breakdown of scores).

Forty typically developing children (31 boys) were recruited from local preschools and schools. Parents of typically developing children and parents of children with autism completed the Social Communication Questionnaire (Rutter, Bailey, & Lord, 2003), a 40-item screening tool for autism. All children in the comparison group scored below the instrument's threshold score for an ASD (15 out of 40; M = 4.30; SD = 3.52), and well below the mean score obtained for the autism group (M = 24.70; SD = 7.04), t (68) = 15.88, p < .001.

Insert Table 2 about here

Measures of verbal and nonverbal ability

The Peabody Picture Vocabulary Test – Third Edition (PPVT-III; Dunn & Dunn, 1997), a measure of receptive vocabulary, was used to assess verbal ability. Four subtests from the Leiter International Performance Scale – Revised version (Leiter-R; Roid & Miller, 1997) were used to estimate nonverbal ability: Matching (a match-to-sample task using pictures of objects and abstract patterns), Associated Pairs (an associative memory task that required children to form associations between pairs of pictured objects), Forward Memory (a visual short-term memory task that involved children copying the examiner's pointing sequence), and Attention Sustained (a visual attention task that entailed identifying specific stimuli among distractor stimuli). The use of these tests were well-suited for children with autism as they involved little or no verbal output on the part of the child; nonetheless, it should be noted that these instruments may tend to overestimate verbal ability and nonverbal ability in this population (Burack, Iarocci, Bowler, & Mottron, 2002; Mottron, 2004). Standard scores are reported in Table 2. Raw scores were used for the purpose of correlational analyses, as they were not adjusted for age and therefore estimated verbal and nonverbal ability rather than IQ.

ToM measures

Three standard false-belief tasks were administered to index ToM. Successful performance on all tasks involved children predicting an action based on an attributed false belief. Children's responses to the false-belief test question were considered valid only if they answered the corresponding memory and reality control questions correctly. In the First-order Unexpected Contents task, based on Perner, Leekam, and Wimmer (1987), children were asked to look inside a familiar container (e.g., a Smarties tube), which contained unexpected contents (e.g., pencils). Upon closing the container, children were asked questions pertaining to their own false-belief ("Before you looked inside, what did you think was in the box?") and to current reality ("What is inside the box really?"). Next, they were introduced to a puppet, Elly, and were asked to predict Elly's false-belief ("What will Elly think is inside the box?") and answer a second control question ("What is in the box really?"). Children completed three trials (Smarties tube – pencils; egg carton – cotton wool; milk carton – elastic bands), the order of which were counterbalanced across children. One point was given to each correctly reported false-belief (total score out of 6).

In the First-order Unexpected Transfer task, modeled on Wimmer and Perner (1983), children witnessed one character either displace or substitute another character's object. In one scenario (displacement trial), children watched one character (e.g., Sarah) place an object (e.g., an apple) in one location (e.g., a bag) and leave the room. While the main character was absent, another character (e.g., Andy) moved the object from one location to another. Children were asked to predict the main character's behavior (e.g., "Where will Sarah look for her apple?") and to answer reality (e.g., "Where is the apple really?") and memory (e.g., "Where was the apple in the beginning?") control questions. In another scenario (substitution trial), children observed one character (e.g., Andy) surreptitiously replace the object (e.g., an apple) with another one (e.g., a banana). Children were then asked similar false-belief (e.g., "What will Sarah think is inside her bag?") and control ("What is really in the bag?" and "What was in the bag in the beginning?") questions. One point was given for each correct response to the false-belief question for 3 displacement scenarios and 3 substitution scenarios, yielding a total score out of 6.

The Second-order Unexpected Transfer task, adapted from Perner and Wimmer (1985), was similar in nature to the First-Order Unexpected Transfer task, though this time, the child observed the main character watching the transfer through a window. Two displacement scenarios were administered. For each story, children were asked a false-belief question (e.g., "Where will Andy think that Sarah will look for her apple?")

as well as reality (e.g., “Where is the apple really?”) and memory (e.g., “Where did Sarah put the apple in the beginning?”) control questions. One point was given to each correctly reported false-belief (total score out of 2).

Both Unexpected Transfer tasks were administered to children in animated video format on a laptop computer, while the Unexpected Contents task was presented ‘live’.

EF measures

Mazes task. This task, taken from the Wechsler Pre-Primary Scales of Intelligence (WPPSI; Wechsler, 1989), assessed planning ability, and required children to complete a series of increasingly difficult mazes. Children had to plan their route and reach the opening of the maze as quickly as they could whilst making minimal errors (i.e., deviating from the correct path). Following published guidelines (Wechsler, 1989), scoring was based upon a combination of accuracy and speed. For each trial, children received two points if they completed the maze correctly within a specified time; points were deducted if children exceeded this time and/or if they made errors. Possible scores ranged between 0 and 26, with high scores representing good planning ability.

Tower of London. This task, originally developed by Shallice (1982), indexed the ability to plan ahead, where the need to generate and maintain a sequence of moves increased with task difficulty. Children were presented with a wooden pegboard consisting of three vertical pegs (one large peg, one medium peg, and one small peg), and three beads (one red, one white, and one black). The large peg could hold three beads, the medium peg could carry two beads, and the small peg could hold just one bead. First, children were asked to arrange the beads in the configuration shown in a picture (i.e., the ‘start state’). Next, they were presented with a different picture of the pegboard showing the beads in a new configuration (i.e., the ‘goal state’), and asked to move the beads from the prearranged sequence to match the goal configuration using as few moves as possible. They were asked to adhere to the following rules: (1) to move only one bead at a time, and (2) not to place any beads on the table. The task began with an easy (1-move) problem-set, and progressively increased in complexity. There were 16 trials in total, 4 trials for each problem set (1-move, 2-move, 3-move, and 4-move). To be credited with passing a given trial, children had to solve it within the minimum number of moves. At least 1 correct solution out of 4 problems was necessary to advance to the next problem set. The number of problems solved within the minimum number of moves was recorded (maximum score of 16); high scores reflect good planning ability.

Set-shifting task. This measure of cognitive flexibility, similar in nature to the Wisconsin Card Sorting Test (Heaton, 1981), was simplified for use with preschool children by Hughes (1998a). It required children to sort cards according to a rule that changed, and assessed their ability to shift flexibly their problem-solving set in response to verbal feedback. There were three decks of 64 cards, each approximately 100mm x 100mm. The cards in each deck differed on two dimensions: (1) color (green/pink, blue/red, or yellow/purple), and (2) shape (hearts/diamonds, squares/moons, or stars/happy faces). Each color pair was associated with a particular picture pair (green/pink hearts/diamonds; blue/red squares/moons; yellow/purple stars/happy faces), and each deck included an equal number of small and large pictures of each type in each color (e.g., green/pink small and large pictures of hearts and diamonds). As such, cards in each deck could be sorted according to three different rules: color, shape, and size.

To begin, children were shown one of the three decks of cards. They were introduced to a teddy and were instructed that they needed to work out which of the cards were teddy’s favorite cards. The child was to put teddy’s favorite cards into a post box, and to place the cards teddy did not like face-down on the table. The experimenter recorded the card (e.g., large blue moon), and the child’s response. Feedback was provided after each trial (e.g., "Yes, that is one of Teddy's favorite cards" or "No, actually, that isn't one of Teddy's favorite cards"). Once six consecutive cards had been sorted correctly or a maximum of 20 trials had been presented, the sorting rule changed. At this point, the child was introduced to a new teddy and a new deck of cards. Unlike in other sorting tasks (e.g., Frye et al., 1995), children were not told explicitly that the rule had changed; this was implicit in the fact that children were presented with a new situation. The order of presentation of rule (color, shape, size) and the deck of cards used (green/pink, blue/red, yellow/purple) were counterbalanced across participants. The dependent variable of primary interest was the total number of trials to criterion across all three rules (out of 60); a low score is indicative of good cognitive flexibility.

Luria's hand-game. This task, originally devised by Luria, Pribram, and Homskaya (1964) to assess inhibitory control in patients with prefrontal lesions, has been used to assess EF in children with autism (Hughes, 1996). Successful performance on this task requires one to hold an arbitrary rule in working memory and inhibit a prepotent response in order to perform a rule-governed motor act. Following the procedure by Hughes (1996, 1998a), two conditions were administered. In the imitation (control) condition, children were asked to imitate the experimenter's hand movements (e.g., make a fist or point a finger). In the conflict (test) condition, children were asked to execute the opposite action to that of the experimenter; that is, when she made a fist, children had to point their finger, and when she pointed her finger, children had to make a fist. In line with Hughes (1996, 1998b), feedback was provided after each trial (e.g., "Yes, you're right! You made a different shape to me"). The five fist and five finger trials in each condition were presented in a randomized order, and the imitation condition was always presented before the conflict condition. Children received one point for each correctly executed action in each condition (out of 10); high scores in the conflict condition reflect good inhibitory control.

General Procedure.

Children were seen for two 1-hour visits, scheduled no more than 2 weeks apart, in a quiet room either in their home or at school. The same female experimenter assessed all children. The PPVT-III and subtests from the Leiter-R were always completed first, while the order of administration of the remaining measures was randomized across participants. Children's responses were scored 'online' during the assessment.

Results

Background data analysis

Table 2 shows descriptive data for the autism and typically developing groups separately. Children in the comparison group were matched closely to the children in the autism group in terms of age, t (68) = .46, p = .50, verbal IQ, t (68) = 1.48, p = .28, and nonverbal IQ, t (68) = .15, p = .70.

Preliminary analysis of scores revealed positive skew in the distribution of scores for all ToM variables in the autism group, and in the distribution of second-order ToM scores in the typically developing group. Square-root transformations were applied to all three ToM variables. These transformations, however, were unsuccessful in normalizing the data, and so nonparametric tests (Mann Whitney U) were used to examine group differences on individual ToM tasks. All EF variables met assumptions regarding normality, with the exception of the imitation condition from Luria's hand-game. This was not a critical component of this task, and so these data were not analyzed further. No outliers were identified for any variable, with the exception of one typically developing child who scored more than 3 SD above the mean on the Mazes task; the results of analyses did not change with the exclusion of this outlier, and therefore analyses are reported on the full data set. Reliability was assessed for the ToM composite (see below): Cronbach's alpha was .90, indicating high internal consistency. It was not feasible to calculate reliability estimates for the executive tasks, as most of these measures incorporate stopping rules as part of their administration. Good reliability and validity, however, has been reported for the Mazes task (Wechsler, 1989).

In order to assist comparison across tasks, scores from the Set-shifting task were recoded so that a high score reflected good performance. Scores on each ToM and EF task were converted to z scores using the typically developing group as the normative standard [(score – $Mean_{control}$) / $SD_{control}$]. All subsequent analyses are performed using the z scores for each variable, although the untransformed means and standard deviations for each variable can be found in Table 3.

Group differences on ToM and EF tasks

Nonparametric analyses showed that children with autism performed significantly worse than typically developing children on the First-order Unexpected Contents, $U = 373.00$, $p < .005$, and Unexpected Transfer, $U = 322.00$, $p < .001$, tasks (see Table 3 for raw scores). No significant differences were found on the Second-order Unexpected Transfer task, $U = 514.50$, $p = .12$, though this is likely to be due to the fact that performance was at floor for both groups of children. Spearman rank-order correlations showed that the z scores for the three ToM scores were correlated significantly within each group (r_s range .44 - .77, all ps < .01). For subsequent analyses, these z scores were averaged to form a ToM composite[3]. Examination of the distribution of scores revealed that the ToM composite met assumptions of normality. An ANOVA confirmed that the children with autism obtained significantly lower ToM composite scores than typically developing children, $F(1, 68) = 14.63$, $p < .001$, $\eta^2 = .18$.

With respect to the individual EF tasks, analysis of variance revealed that children in the autism group performed significantly worse on Luria’s hand-game, $F(1, 68) = 5.32$, $p < .05$, $\eta^2 = .07$, the Tower of London task, $F(1, 68) = 12.53$, $p < .001$, $\eta^2 = .16$, and the Set-shifting task, $F(1, 68) = 9.60$, $p < .005$, $\eta^2 = .12$, relative to comparison children (see Table 3). No significant group differences, however, were found on the Mazes task, F (1, 68) = 0.82, ns.

Insert Table 3 about here

Despite the significant group differences on ToM and most EF variables, inspection of the data indicated that the two groups' distributions overlapped considerably (see Figure 1). To examine this further, the percentage of the autism group that displayed an 'impairment' (i.e., scored more than one SD below the mean of the typically developing group) was calculated for each task. These calculations revealed that 67% of the autism group fell more than one SD below the mean of the typically developing group on the ToM composite. Approximately half the group of children with autism displayed executive impairments: 33%, 43% and 50% of the autism group obtained scores more than one SD below the mean of the typically developing group on Luria's hand-game, the Tower of London task, and the Set-Shifting task, respectively.

Insert Figure 1 about here

Correlational analyses

Effects of age, verbal ability, and nonverbal ability. Analyses revealed significant correlations between most scores on cognitive measures and age, verbal ability, and nonverbal ability, for both the autism (see Table 4) and typically developing (see Table 5) groups. There were two exceptions to this pattern: ToM composite scores were unrelated to chronological age in children with autism, and Set-shifting scores were not associated with age or nonverbal ability in typically developing children.

EF measures. Despite the fact that many researchers emphasize the componential nature of EF (e.g., Hughes, 1998a; Pennington & Ozonoff, 1996), it is encouraging that most EF variables were significantly related in the autism (see Table

4) and typically developing (see Table 5) groups; poor executive control was consistently represented in low scores on Luria's hand-game, the Mazes task, the Tower of London task, and the Set-shifting task. These relationships generally remained significant when the effects of age were partialled out. When the effects of age, verbal ability and nonverbal ability were adjusted for, only the following correlations remained significant in the autism group: Luria's hand-game and Set-shifting scores, Mazes and Set-shifting scores, Mazes and Tower of London scores, and Mazes and Luria's hand-game scores. In the typically developing group, correlations involving Luria's hand-game and Mazes scores, and Luria's hand-game and Set-Shifting scores remained significant.

In light of the significant intercorrelations between $\underline{z}$ scores for the executive tasks, an EF composite was created by taking the mean $\underline{z}$ scores for all four tasks – the same method as the one used to create the ToM composite. Since one of the aims of the study was to examine the relationship between ToM and componential EF skills, subsequent analyses are performed on the $\underline{z}$ scores of the individual executive tasks and the EF composite variable.

Relationship between ToM and EF measures. Table 4 shows that all raw correlations between EF and ToM were significant and of high magnitude in the autism group; ToM scores were positively associated with scores on the EF composite, Luria's hand-game, the Mazes task, the Tower of London task, and the Set-shifting task. Because individual differences in ToM and EF variables were related significantly to general and individual differences in age and ability, correlational analyses examining the relation between ToM and EF were re-conducted, partialling out the effects of these variables (see Table 4). When age was partialled out, scores on all four EF measures remained significantly correlated to ToM scores. These correlation coefficients dropped in magnitude when subsequent partial correlations involving age and verbal ability, and then age, verbal ability, and nonverbal ability, were performed. ToM scores remained significantly correlated with the EF composite, r (25) = .43, p < .05, and Set-shifting scores, r (25) = .45, p < .05, but were no longer associated with scores on Luria's hand-game, the Mazes task, or the Tower of London task.

Insert Table 4 about here

In the typically developing group, ToM scores were initially significantly related to scores on the EF composite, Luria's hand-game, the Mazes task, and the Tower of London task, but not with scores on the Set-shifting task (see Table 5). Unexpectedly, most correlations between ToM and EF variables (including the EF composite) dropped to nonsignificance when age, verbal ability, and nonverbal ability were adjusted for, apart from a significant correlation between ToM and Tower of London scores, r (35) = .35, p < .05. The paucity of significant ToM-EF correlations was surprising as numerous studies have demonstrated links between ToM and EF in typical development. One possibility for the lack of significant ToM-EF correlations could be the uneven number of male and female participants in the typically developing group. Girls have been shown to outperform boys on some EF tasks (e.g., Carlson & Moses, 2001), and so gender is sometimes partialled out of the relationship between ToM and EF. Supplementary correlational analyses with gender partialled out (along with age, verbal ability, and nonverbal ability) produced very few changes to the correlation coefficients, and importantly, did not change the significant ToM-Tower of London correlation. Another possible reason for the failure to demonstrate significant ToM-EF correlations independent of age and ability could have been the inclusion of children beyond 5 years in the current study. Indeed, the majority of studies have tended to focus upon the ToM-EF relation during the period in which these two abilities emerge (3 – 5 years of age). To investigate this further, the typically developing group was split about the median with respect to chronological age, and correlational analyses (with partial correlations) were re-conducted for the younger (M age = 4 years 6 months) and older (M age = 6 years 3 months) groups separately. When age, verbal ability, and nonverbal ability were partialled out, ToM scores remained significantly correlated to Tower of London scores in the younger age group, $r(15) = .50$, $p < .05$, but no significant ToM-EF correlations persisted in the older age group, all ps > .52.

Insert Table 5 about here

Pattern of ToM-EF impairments in the autism group

To examine the pattern of ToM-EF impairments in children with autism, the percentage of children who displayed no impairments (i.e., intact performance on ToM and EF tasks), dual impairments (i.e., impaired performance on ToM and EF tasks), or impairments in one domain only, were calculated. Of course, dissociations could occur in either of two directions (see Table 1 for predictions): impaired ToM performance with intact EF performance, (which would support Russell's executive account), or intact ToM performance with impaired EF performance (which would be consistent with Perner's metarepresentational account). Note that an 'impairment' on any task was defined in relation to the typically developing group in the same way as before.

Analyses using ToM and EF composite scores revealed that one third of the autism group consistently demonstrated intact ToM and EF, while a significant percentage of the group (40%) displayed impairments in both cognitive domains. With respect to the dissociations, the results were striking: 27% ($n = 8$) of children with autism showed impaired ToM performance with intact EF performance; conversely, examination of dissociations in the reverse direction revealed that no child showed intact ToM with impaired EF. This pattern of ToM-EF impairments is mirrored in analyses involving the individual executive tasks (see Table 6). Thus, the presence of impaired ToM was not necessarily coupled with executive impairments in this group of children with autism; the presence of an EF impairment, however, always occurred in combination with a ToM impairment.

To check the possibility that this pattern of results did not arise due to the particular definition of ‘impairment’ used here (which might be considered somewhat arbitrary), the analyses above were repeated using two alternative criteria for ‘impairment’: (1) scores more than one semi-interquartile range below the median of the typically developing group; and (2) scores more than the 10^{th} percentile of the typically developing group. Reassuringly, a similar pattern of results when either criterion was used, providing support for Russell’s executive account.

Insert Table 6 about here

It is noteworthy that not all children with autism showed impairments on ToM or EF. Factors such as chronological age (e.g., Yirmiya, Erel, Shaked, & Solomonica-Levi, 1998) and verbal IQ (e.g., Happé, 1995) have been shown to play an important role in successful ToM performance by children with autism. Supplementary analyses, therefore, were conducted to determine whether children who showed no ToM/EF impairments could be differentiated in terms of age, intellectual functioning, or severity of autistic symptoms from children showing one or two impairments in ToM/EF. To minimize the number of statistical comparisons, ToM and EF composite scores were used in these analyses.

First, children were grouped according to the number of impairments they displayed. Next, analyses of variance were conducted on age, verbal IQ, nonverbal IQ, and total ADI-R scores with group [no ToM/EF impairments ($\underline{n}$ = 10), one impairment (in ToM; $\underline{n}$ = 8), two impairments (in ToM and EF; $\underline{n}$ = 12)] as the between-participants factor. No significant group differences were found for chronological age, nonverbal IQ, or symptom severity (all ps ranged between .13 and .53). Significant differences, however, were demonstrated on verbal IQ, F (2, 27) = 14.76, $p < .001$. Post-hoc paired comparisons (with Bonferroni correction) confirmed that children with autism who displayed intact ToM and EF invariably obtained significantly higher verbal IQ scores (M = 110.90) than children who had one impairment (in ToM) only (M = 94.62; $p <$ .001), or impairments in both ToM and EF (M verbal IQ = 95.25; $p < .001$).

The significant effect of verbal IQ prompted the following question: could it be the case that verbal IQ mediates the ToM-EF relationship in autism? It is well-documented that language level plays a role in performance on both ToM (e.g., Happé, 1995) and EF tasks (e.g., Hughes, 1998a). To test the possibility that verbal IQ might mediate the ToM-EF connection in autism, a series of regression analyses were conducted. In line with Baron and Kenny (1986), verbal IQ would function as a mediator if: (1) EF was a significant predictor of ToM; (2) EF was a significant predictor of verbal IQ (the potential mediator); (3) verbal IQ was a significant predictor of ToM; and (4) the effect of EF was significantly reduced (indeed, reduced to zero in the case of total mediation), while the effect of the mediator (verbal IQ) was upheld, when EF and verbal IQ were entered together as predictors of ToM.

Results from regression analyses revealed that EF was a significant predictor of ToM (ß = .62, ΔR^2 = .39, $p < .001$) and verbal IQ (ß = .47, ΔR^2 = .22, $p < .01$), and that verbal IQ was a significant predictor of ToM (ß = .62, ΔR^2 = .38, $p < .001$). When EF and verbal IQ were examined together as predictors of ToM, the effects of both EF (ß = .42, $p < .01$) and verbal IQ (ß = .42, $p = .01$) were attenuated, but remained significant. A stepwise regression analysis in which verbal IQ was entered in the first step and the EF composite variable was entered in the second step showed that EF made a unique contribution (ΔR^2 = .14, $p < .01$) to the variance in ToM once the effects of verbal IQ were accounted for. Therefore, Baron and Kenny’s fourth condition (with respect to total mediation) was not satisfied, rendering it unlikely that verbal IQ alone could explain the ToM-EF link in autism.

Discussion

Links between ToM and EF

Previous studies have demonstrated a robust link between ToM and EF in older children and adolescents with autism, independent of age and ability (Colvert et al., 2002; Joseph & Tager-Flusberg, 2004; Ozonoff et al., 1991). The present findings corroborate and extend these findings to include young children with autism: individual differences in false-belief prediction were significantly related to individual differences in executive control (specifically to set-shifting skills), once variance attributable to age, verbal ability, and nonverbal ability had been adjusted for. Thus, ToM seems to be reliably linked to aspects of executive control throughout early childhood and adolescence for individuals with autism.

For typically developing children, most correlations between scores on ToM and EF measures dropped to nonsignificance when general and individual differences in age and ability had been partialled out. The exception to this was a significant correlation between ToM and higher-order planning ability. This pattern of results was unexpected, as the majority of correlational studies with typically developing preschoolers report robust associations between ToM and several aspects of EF (see Perner & Lang, 2002, for a review). The size of the typically developing group here is somewhat smaller than those of other correlational studies (e.g., Carlson & Moses, 2001) and might explain the lack of significant correlations in the comparison group. Another potential reason might be the inclusion of children beyond the age of 5 years in the current study. Close examination of the ToM-EF correlations in younger and older children revealed that the pattern of ToM-EF correlations (with age and ability partialled out) in the group overall reflected primarily the pattern of correlations in younger but not older children. While these post-hoc analyses should be treated with caution, they do raise the possibility that ToM and EF might be crucially linked at an earlier stage of (typical) development when these two abilities begin to emerge (i.e., around age 4), but fail to influence each other beyond the point at which conceptual understanding is largely in place (though see Perner, Kain, & Barchfeld, 2002, for significant associations between second-order false-belief performance and components of EF).

ToM and EF in autism: examining issues of developmental primacy

Correlational analyses are important for establishing a relation between ToM and EF. They convey little, however, about the underlying nature of this relationship. The present study was also designed to provide clues concerning the developmental primacy of ToM or EF by examining the particular pattern of ToM-EF impairments in children with autism. As discussed above, Perner and his colleagues (1998, 2000; Perner & Lang, 1999, 2000) have argued that developments in understanding the representational nature of mind lead to improved self-control; by contrast, Russell (1996, 1997, 2002) has claimed that advancements in the child's first-person experience of the intentional nature of action leads to developments in mental-state awareness. Recall that each position predicts a different pattern of ToM-EF impairments in clinical populations (Perner & Lang, 1999, 2000): Perner's theory does not permit the possibility of impaired ToM with intact EF, while Russell's theory does not permit the possibility of impaired EF with intact ToM (see Table 1).

Inspection of the pattern of ToM-EF impairments in the autism group of the present study led to an intriguing set of findings. First and foremost, the number of children in the diagonal cells – those who displayed impairments in both ToM and EF, or those who displayed impairments in neither domain – offers compelling evidence of the relation between EF and ToM in autism. Second, examination of the asymmetry between EF and ToM (i.e., the number of children in the off-diagonal cells) revealed that these domains were dissociable in one direction only – impaired ToM with intact EF. These data speak against Perner's (1998, 2000) thesis, and instead offer support to Russell's opposing view that EF is an important factor for the development of ToM. Moreover, the pattern of ToM-EF impairments was moderated by verbal IQ, such that children with higher verbal IQ scores showed fewer impairments than children with lower verbal IQ scores. Indeed, the fact that executive abilities and verbal IQ made independent contributions to ToM scores in regression analyses is suggestive of the important role that both variables play in the development of ToM in autism.

Before embarking upon a theoretical discussion of these results, it is important to note that the pattern reported herein should be attended by several caveats. First, the EF and ToM tasks were not equated for difficulty, and it is possible therefore that differences in the level of difficulty of the two sets of tasks could explain the pattern of dissociations (cf. Perner & Lang, 2000). This seems unlikely, however, as the same tasks have been used previously to examine ToM-EF relations in typically developing (e.g., Hughes, 1998a, b) and hard-to-manage (e.g., Hughes et al., 1998) children. Also, performance by children in the present study was neither at floor nor at ceiling for any ToM or EF measure, and inspection of the distribution of z scores in the typically developing group indicated that the ToM and EF tasks showed similar variability. Second, the criterion for defining 'impairment' in the autism group could be considered somewhat arbitrary. Yet, a stringent criterion was adopted in the present study (i.e., scoring more than one SD below the mean of the typically developing group), which was argued to be more appropriate than the liberal definition used by Ozonoff et al. (1991) (i.e., scoring below the mean of the typically developing group), and the pattern of results remained unchanged when additional alternative criteria were used. Third, it is plausible that additional measurement issues (e.g., reliability and validity) may have contributed to the resulting pattern of ToM-EF impairments. High internal consistency was reported for the ToM tasks, and scores on EF measures were robustly intercorrelated in the autism group, indicative of good convergent validity. The reliability of the scores for some EF tasks, however, remains uncertain. High reliability has been reported for EF tasks in individuals with autism (Ozonoff, 1995), yet it remains possible that lower reliability of scores from the current EF measures played a role in the inability to demonstrate pervasive EF impairments in the autism group. Finally, this study was not longitudinal and as such, caution is warranted with respect to the kinds of inferences that one can draw from the resulting pattern of ToM-EF impairments this group of children with autism.

Despite these concerns, the pattern of ToM-EF impairments found here does provoke reconsideration of the theoretical debate surrounding issues of developmental primacy of ToM-EF in autism. Before turning to Russell's account, it is worth considering whether the pattern of ToM-EF impairments demonstrated in the current study is also consistent with alternative explanations for the developmental link between ToM and EF. As outlined above, two such alternative accounts exist, both of which claim that a third (domain-general) factor, common to ToM and EF, underlies the association between these two domains in typically developing children and children with autism (Ozonoff et al., 1991; Zelazo et al., 2002). Note that any plausible explanation would need to explain (a) the significant correlation between ToM and EF, (b) the dissociation of ToM and EF in one direction only, and (c) the important role of verbal IQ.

According to the first of these accounts, put forth by Ozonoff and colleagues (1991; see also Bishop, 1993), parallel improvements in ToM and EF in typical development and the co-occurrence of ToM and EF deficits in autism is because both functions are mediated by adjacent structures in the prefrontal cortex (ToM: medial prefrontal cortex; EF: dorsolateral and ventrolateral prefrontal cortical areas; Kain &

Perner, 2005). Accordingly, correlations between ToM and EF emerge as a result of neuroanatomic proximity, although they are not causally related to each other. In light of the pervasiveness of EF deficits in their autism sample, Ozonoff et al. (1991) argued that executive deficits were primary in the etiology of autism. This is in direct conflict with the present data, however, where ToM impairments were found to be more pervasive than EF impairments. This contrast raises the possibility that ToM (rather than EF) might be more vulnerable in young children with autism. A developmental story could be constructed in an attempt to reconcile these contradictory findings. It is possible that independent impairments might emerge at different periods of development, and as such, a ToM impairment emerges as the core deficit early on during development (consistent with the current data) but as the child progresses, ToM abilities 'catch up' to typically developing children, while executive impairments persist and become more apparent (and therefore more primary) over time (in line with Ozonoff et al.'s data). Indeed, autism-specific deficits in EF have been reported at 5 ½ years (Dawson, Meltzoff, Osterling, & Rinaldi, 1998; McEvoy, Rogers, & Pennington, 1993) but not at 4 years (Griffith et al., 1999), consistent with the suggestion that children with autism may 'grow into' an EF deficit with development.

An equally plausible explanation concerns the possibility of diverging developmental trajectories for ToM and EF in typical development, rather than any developmental changes in ToM/EF abilities in children with autism. The normative development of EF is thought to extend well into adolescence (e.g., Diamond, 2002) and may be more late-maturing than ToM abilities. One might expect, therefore, to find greater disparity between the groups with respect to executive skills at later (as opposed to earlier) stages of development due to the continuing maturation of EF in typically developing children.

Despite such encouraging analysis, Ozonoff et al.'s (1991) view is weakened by the fact that it sheds no light upon the importance of verbal IQ in the development of ToM in autism. This is not the case, however, for the second alternative account, Cognitive Complexity and Control (CCC) theory (Frye et al., 1995; Zelazo et al., 2002). This theory posits that domain-general changes in the ability to deal with complex rules underpin the typical development of EF and ToM. By extension, children with autism fail tests of false-belief and cognitive flexibility as a result of the tasks' common executive or rule-use requirements (Zelazo et al., 2002). According to CCC theory, language plays an important role in the conscious control over action – natural language is held to be the medium through which higher-order ('if-if-then') rules are formulated, and is crucial to recursive thought (Zelazo, 2004). Consequently, it is easy to appreciate how poor language skills might impact on a child's ability to follow verbal instructions (in the form of 'if-if-then' rules), and in turn adversely affect performance on EF tasks. Another aspect of the present findings supports CCC theory: false-belief understanding was significantly related to Set-shifting performance in the autism group, over and above the effects of age and ability, though this correlation was not significant in the typically developing group. Most problematic for this theory is the failure to account for the existence of dissociations between ToM and EF in the autism group. It might have been reasonable to expect some 'noise' to be present in the current data (i.e., for some children to fall on the off-diagonal cells), given that the rule-use requirements of the ToM and Set-shifting tasks were not perfectly matched. Such 'noise', however, should have been evenly distributed across both off-diagonal cells, which, of course, was not the case in the present study. It remains difficult, then, for CCC theory to explain the presence of ToM-EF dissociations in one direction only: impaired ToM with intact EF.

A few studies have suggested that EF impairments in autism are mediated strongly by language abilities (Bishop & Norbury, 2005; Liss et al., 2001; though see

Joseph, McGrath, & Tager-Flusberg, 2005), leading one to question whether verbal IQ could in fact be the putative third factor mediating the ToM-EF relation in autism. The results from the regression analyses, however, suggest that verbal IQ (as indexed by scores on a test of receptive vocabulary) did not mediate completely the relationship between ToM-EF: EF composite scores made a significant unique contribution to variance in ToM composite scores in the autism group, over and above verbal IQ.

A more parsimonious explanation postulates functional dependency between EF and ToM. Russell's (1996, 1997, 2002) executive account – that rudimentary EF is crucial for the development of ToM – explains well the significant association between false-belief understanding and aspects of EF in autism in addition to the pattern of ToM-EF impairments in the autism group. These data fit alongside other evidence from autism. In a single-case study, Baron-Cohen and Robertson (1995) reported that a child with autism (aged 9 years) failed several ToM tasks but performed well on tasks of inhibitory control. In a recent training study, Fisher and Happé (2006) demonstrated improvements in ToM performance for children with autism (M age ≈ 10 years) who had been trained on EF two months earlier, though no similar improvements were made on EF tasks for children who had been trained initially on ToM. While this result is consistent with the notion that early EF skills contribute to the development of ToM, its interpretation is tempered by the fact that EF training had no direct effect on executive performance at the two-month follow-up.

Russell's theory also accounts for the important role of verbal IQ in the developmental relationship between ToM and EF in autism. Russell (1996, 1997, 2002; see also Bíró & Russell, 2001) makes the case that all of the executive tasks on which individuals with autism do poorly require maintenance of arbitrary rules (i.e., rules that have no clear rationale) in working memory. For example, success on the Set-shifting task required the child to hold in mind an arbitrary rule (e.g., "sort by the new dimension and ignore the old" Russell, 1997, p. 285), which, Russell has argued, would be strengthened if the child formed a verbal representation of the rule. For Russell, then, inner speech is fundamental for regulating and controlling one's behavior. Two studies support this idea, reporting evidence that children with autism fail to use verbal rehearsal strategies on executive tasks (Joseph, Steele, Meyer, & Tager-Flusberg, 2005; Whitehouse, Maybery, & Durkin, 2006). It seems plausible, therefore, that children with higher verbal IQ might have performed well on EF tasks relative to children with lower verbal IQ by virtue of their use of inner speech to regulate executive control over action. This hypothesis certainly deserves further attention.

The current findings are consistent with the notion that executive deficits present early in life may seriously limit the child's ability to reason about the mental state of others. For Russell, executive skills have a direct impact on the development of ToM. Another, less controversial account put forward by Hughes (1998b) suggests that the ToM-EF relation could be less direct than previously thought. Hughes (1998b; Hughes, White, Sharpen, & Dunn, 2000) conjectures that social interaction might mediate (partially) the relation between EF and ToM; poor executive control could have an adverse effect on a child's ability to regulate his/her behavior during social interactions, which could, in turn, limit the quality and quantity of such interactions (e.g., the nature and number of friendships with same-aged peers). This could have a detrimental effect on the development of mental-state awareness. This explanation is certainly plausible, particularly in children with autism whose social interactions are already limited. One possible next step would be to examine directly the link between executive skills and social interaction, using direct observational measures with peers.

One additional factor that might moderate the link between ToM and EF is diagnostic status. Assessment of the underlying nature of the ToM-EF relation in other clinical populations reveals a pattern of ToM-EF impairments that is distinct from the one found in autism. Perner and Lang (2002) re-analyzed data from Tager-Flusberg, Sullivan, and Boshart (1997) and reported the opposite ToM-EF dissociation to the one reported here: children with Williams syndrome (n = 3) and Prader-Willi syndrome (n = 3) performed well on two ToM tasks but poorly on two EF tasks (i.e., intact ToM with impaired EF). The small sample sizes reported in this study render the results difficult to interpret. Perner et al. (2002) demonstrated a similar dissociation in a group of preschool children ‘at-risk’ for Attention Deficit/ Hyperactivity Disorder (ADHD), such that children displayed relatively unimpaired ToM relative to comparison children, yet were impaired on EF tasks (specifically planning ability) (see also Charman, Carroll, & Sturge, 2001, for parallel findings in children diagnosed with ADHD).

While this may seem initially puzzling, the contradictory pattern of findings might be resolved by appealing to the view that development itself will play an important role in shaping the trajectories of different cognitive functions (Bishop, 1997; Karmiloff-Smith, 1998). On this view, the resulting pattern of ToM-EF impairments must be considered in light of abnormal initial states; early executive dysfunction might be one reason for poor mental-state reasoning in autism, but impairments in rudimentary EF might not necessarily lead to poor ToM for other developmental disorders.

The conflicting pattern of results should also be considered in light of the multifaceted nature of EF – a construct that comprises a complex set of dissociable skills, including higher-order planning and sequencing, cognitive flexibility, inhibitory control and working memory. Different developmental disorders have been associated with deficits in specific executive skills: individuals with autism show striking deficits on tests of planning and cognitive flexibility, while individuals with ADHD show more pronounced impairments on tasks of inhibitory control (see Pennington & Ozonoff, 1996, for a review). This raises the possibility that deficits in specific aspects of EF could carry diverging implications for a child’s emerging understanding of mind, which could provide an additional account of the conflicting patterns of ToM-EF impairments in distinct developmental disorders.

One final point to highlight is the fact that one third of children with autism passed ToM and EF tasks to a level consistent with their age and ability. Some authors have argued that successful performance on laboratory tests does not necessarily indicate underlying competence. It might, for example, be the case that these ‘passers’, armed with sufficient language skills and good executive skills, are able to ‘hack out’ solutions to problems that require reasoning about others’ mental states (Frith, Morton, & Leslie, 1991; Happé, 1993; Tager-Flusberg, 2001). The present data are unable to distinguish between performance and competence in this sample of children with autism. One possibility for future research would be to establish directly whether the ToM and EF skills demonstrated in an experimental setting by some young children with autism do indeed translate into competence in real-life everyday social interactions.

In conclusion, this study addressed theoretical questions concerning the developmental relationship between ToM and EF. The present results provide strong evidence for a link between ToM and EF in autism, and further, point towards the possibility that executive control may be an important limiting and enabling factor in the young autistic child’s developing understanding of other minds. Confidence in the current data is warranted given the relatively large groups of children with autism and typically developing children tested; the restricted age range of the participants; the use of a variety of developmentally appropriate tasks used to assess ToM and EF; and the focus on within-group heterogeneity in ToM and EF performance in the autism group. These findings, however, should not yet be taken as conclusive. It is certain that the ToM-EF relation in autism is complex and multifactorial. It will be important to establish precisely how poor executive abilities affect the development of ToM; that is, whether poor EF affects the rate at which children acquire ToM skills, or whether it affects qualitatively the final stages of ToM development, or both. Longitudinal studies will be crucial for mapping the developmental trajectories of EF and ToM abilities, and for pinpointing whether EF and language skills are in fact important building blocks for the later development of ToM in autism.

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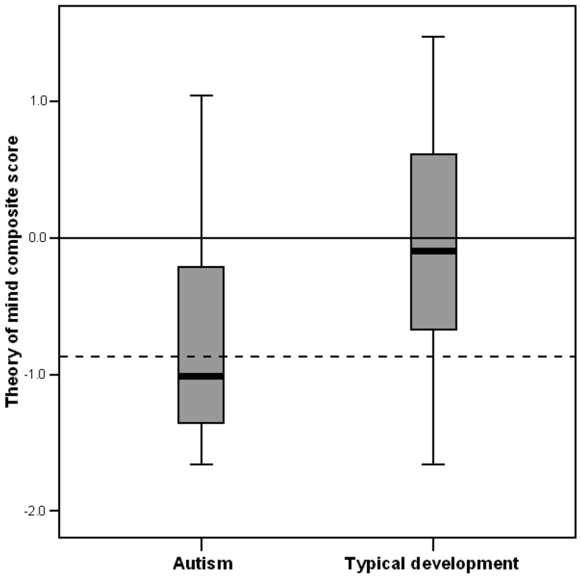
Footnotes

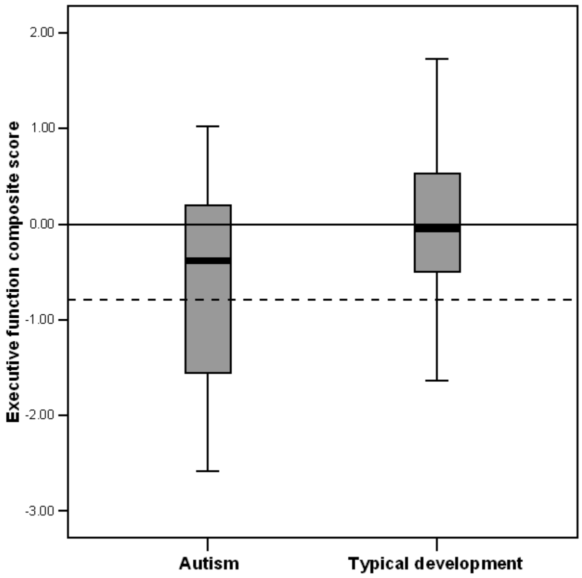
1. Interestingly, Perner, Kain, and Barchfeld (2002) claim that Hughes's (1998b) finding is in fact consistent with Perner's own metarepresentational account. They argue that "this finding might indicate earlier application of a theory of mind for the online use of self-control than for attributing mental states to others" (p. 144).
2. It is important to note that while deficits in first-order ToM were displayed by only half of Ozonoff et al.'s sample of individuals with autism, impairments in second-order ToM were in fact almost universal (87%).
3. To check that the inclusion of the second-order ToM scores did not adversely affect the pattern of results reported herein, a first-order ToM composite was also created (by taking the mean of the z scores from the two first-order ToM tasks) and all analyses were conducted using this composite variable. The pattern of results remained unchanged.

Figure Captions

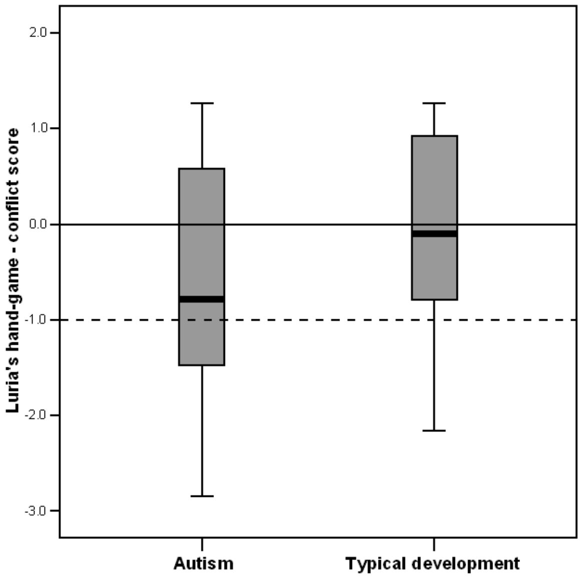
Figure 1. Box plots showing performance on (a) the theory of mind (ToM) composite, (b) the executive function (EF) composite, (c) Luria's hand-game, (d) the Tower of London task, and (e) the Set-shifting task for children with autism and typically developing children. The solid black lines bisecting each rectangle represent the medians of the distributions. The vertical rectangle for each group shows the distribution of the middle 50% of scores, and the 'whiskers' attached to both ends of these rectangles extend out to include 100% of the data. The solid black line intersecting the Y axis represents the mean score of the typically developing group, while the dotted line intersecting the Y axis represents one SD below the mean score of the typically developing group for the ToM tasks, EF tasks, Luria's hand-game, the Tower of London task, and the Set-shifting task. Note that the SD of the typically developing group on the (a) ToM and (b) EF composites differs slightly from -1, and reflects the fact that the z scores have been averaged across several individual ToM/EF tasks.



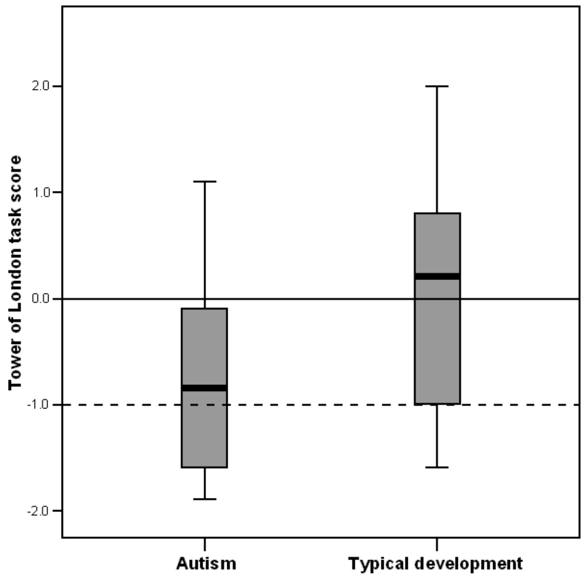
(a)



(b)

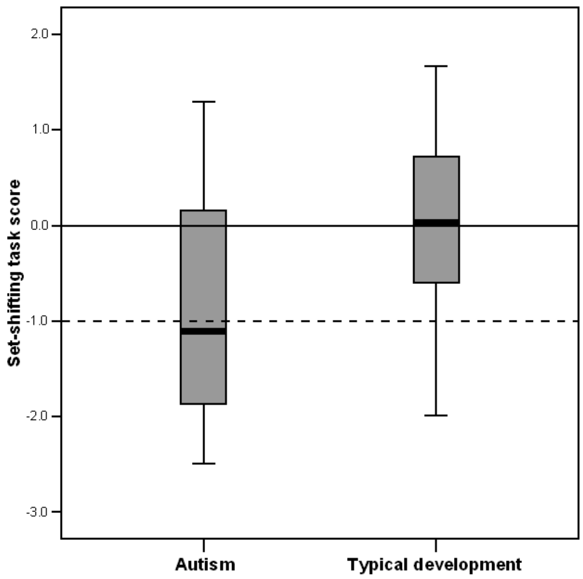


(c)



(d)

<u>Figure 1.</u>



(e)

Figure 1 cont.

Table 1. Contingency tables showing predicted patterns of theory of mind (ToM)-executive function (EF) impairments based upon (a) Perner's theory (i.e., that ToM is a prerequisite for EF) and (b) Russell's theory (i.e., that EF is a prerequisite for ToM).

(a)

		EF	
		impaired	intact
ToM	impaired	✓	✗
	intact	✓	✓

(b)

		EF	
		impaired	intact
ToM	impaired	✓	✓
	intact	✗	✓

Table 2. Descriptive statistics for chronological age, verbal IQ, nonverbal IQ, Social Communication Questionnaire (SCQ) scores, and Autism Diagnostic Interview – Revised (ADI-R) scores in the autism (N = 30) and typically developing (N = 40) groups separately.

	Group	
	Autism (n = 30) M (SD) range	**Typical development (n = 40)** M (SD) range
Age (in months)	67.60 (11.65) 49 – 88	65.70 (11.47) 48 – 88
Verbal IQ	100.03 (10.55) 85 – 122	103.25 (9.92) 75 – 121
Performance IQ	113.87 (13.73) 85 – 141	112.52 (14.47) 91 – 143
SCQ total score	24.70 (7.04) 12 – 36	4.30 (3.52) 0 – 11
ADI-R total score	41.33 (10.88) 21 – 60	
ADI-R abnormal development score (cut-off = 1)	3.70 (1.12) 1 – 5	
ADI-R social interaction score (cut-off = 10)	17.40 (5.90) 4 – 28	
ADI-R communication score (cut-off = 8)	13.50 (4.58) 5 – 22	
ADI-R repetitive behaviours score (cut-off = 3)	6.73 (2.68) 2 – 12	

Table 3. Group means for theory of mind (ToM) and executive function (EF) variables. Note that although the untransformed means and standard deviations are reported here, analyses were performed using the z scores of each variable.

		Group	
Domain	**Measure**	**Autism (n = 30)** M (SD) range	**Typical development (n = 40)** M (SD) range
ToM	1st-order Unexpected contents task (out of 6)	2.53 (2.27) 0 – 6	4.35 (1.46) 0 – 6
	1st-order Unexpected transfer task (out of 6)	1.76 (1.91) 0 – 6	3.27 (2.22) 0 – 6
	2nd-order Unexpected transfer task (out of 2)	.10 (.30) 0 – 1	.40 (.77) 0 – 2
EF	Luria's hand-game (out of 10)	7.27 (1.74) 4 – 10	8.15 (1.46) 5 – 10
	Mazes task (raw score)	14.50 (5.04) 4 – 22	15.38 (3.00) 10 – 25
	Tower of London (# prob. solved in min. moves)	6.63 (2.78) 3 – 13	9.30 (3.34) 4 – 16
	Set-shifting task (total no. trials taken)	43.70 (9.64) 27 – 57	37.22 (7.92) 24 – 53

Table 4. Pearson correlation coefficients between all theory of mind (ToM) and executive function (EF) variables in the autism group (N = 30).

Correlation	Measure	ToM composite	EF composite[a]	Luria's hand-game	Mazes task	Tower of London	Set-shifting task	Chronological age	Verbal ability
Full (df = 30)	EF composite	.62**	-						
	Luria's hand-game	.49**	.71**	-					
	Mazes task	.54**	.80**	.66**	-				
	Tower of London	.47**	.65**	.43*	.69**	-			
	Set-shifting task	.63**	.78**	.72**	.70**	.57**	-		
	Chronological age	.24	.53**	.37*	.49**	.52**	.44*	-	
	Verbal ability	.48**	.67**	.53**	.56**	.63**	.59**	.68**	-
	Nonverbal ability	.47**	.71**	.60**	.55**	.75**	.62**	.67**	.72**
Age partialled (df = 27)	EF composite	.60**	-						
	Luria's hand-game	.44**	.65**	-					
	Mazes task	.49**	.73**	.58**	-				
	Tower of London	.42*	.52**	.29	.58**	-			
	Set-shifting task	.60**	.72**	.67**	.62**	.44*	-		
Age and verbal ability partialled (df = 26)	EF composite	.49**	-						
	Luria's hand-game	.32	.57**	-					
	Mazes task	.40*	.68**	.52**	-				
	Tower of London	.27	.40*	.14	.51**	-			
	Set-shifting task	.50**	.64**	.60**	.55**	.31			
Age, verbal & nonverbal ability partialled (df = 25)	EF composite	.43*	-						
	Luria's hand-game	.25	.49**	-					
	Mazes task	.37	.68**	.48*	-				
	Tower of London	.16	.27	-.08	.48*	-			
	Set-shifting task	.45*	.59**	.54**	.52**	.16	-		

** Significant at the 0.01 level (2-tailed)
* Significant at the 0.05 level (2-tailed)
[a] Correlations between the EF composite and individual EF tasks are item-total corrected.

Table 5. Pearson correlation coefficients between all theory of mind (ToM) and executive function (EF) variables in the typically developing group (N = 40).

Correlation	Measure	ToM composite	EF composite[a]	Luria's hand-game	Mazes task	Tower of London	Set-shifting task	Chronological age	Verbal ability
Full (df = 40)	EF composite	.55**	-						
	Luria's hand-game	.55**	.71**	-					
	Mazes task	.35*	.64**	.67**	-				
	Tower of London	.56**	.64**	.58**	.57**	-			
	Set-shifting task	.25	.40**	.40*	.27	.37*	-		
	Chronological age	.64**	.57**	.62**	.58**	.48**	.10	-	
	Verbal ability	.54**	.68**	.63**	.53**	.65**	.33*	.70**	-
	Nonverbal ability	.54**	.62**	.66**	.64**	.57**	.06	.76**	.67**
Age partialled (df = 37)	EF composite	.28	-						
	Luria's hand-game	.24	.59**	-					
	Mazes task	-.04	.49**	.49**	-				
	Tower of London	.38*	.51**	.41**	.41**	-			
	Set-shifting task	.24	.45**	.44**	.26	.36*	-		
Age and verbal ability partialled (df = 36)	EF composite	.24	-						
	Luria's hand-game	.20	.52**	-					
	Mazes task	-.08	.46**	.45**	-				
	Tower of London	.35*	.40**	.29	.36*	-			
	Set-shifting task	.20	.34*	.36*	.21	.22			
Age, verbal & nonverbal ability partialled (df = 35)	EF composite	.23	-						
	Luria's hand-game	.20	.49**	-					
	Mazes task	-.10	.43**	.40*	-				
	Tower of London	.35*	.36*	.23	.30	-			
	Set-shifting task	.21	.44**	.42**	.28	.28	-		

** Significant at the 0.01 level (2-tailed)

* Significant at the 0.05 level (2-tailed)

[a] Correlations between the EF composite and individual EF tasks are item-total corrected.

Table 6. Contingency tables showing percentage of children with autism (n = 30) who displayed impaired/intact theory of mind (ToM) and executive control for (a) Luria's hand-game, (b), the Tower of London task, and (c) the Set-shifting task.

(a)

		Luria's hand-game performance		Total
		impaired	intact	
ToM	impaired†	33	33	67
performance	intact	0	33	33
Total		33	67	100

(b)

		Tower of London performance		Total
		impaired	intact	
ToM	impaired†	43	23	67
performance	intact	0	33	33
Total		43	57	100

(c)

		Set-shifting performance		Total
		impaired	intact	
ToM	impaired†	50	17	67
performance	intact	0	33	33
Total		50	50	100

† Note: children were considered 'impaired' on any given task if they scored more than one standard deviation above/below the mean of the typically developing group.