EXECUTIVE FUNCTION AND THEORY OF MIND

by

FAYEZA S. AHMED

(Under the Direction of L. Stephen Miller)

ABSTRACT

This thesis examined the relationship between Executive Function (EF) and Theory of Mind (ToM). EF consists of higher-order cognitive processes (Carlson, Mandell, & Williams, 2004) that encompass processes involved in goal-oriented behavior, such as planning and sequencing (Royall et al., 2002). ToM refers to the ability to understand the views and beliefs of another person (Baron-Cohen, 1988). This thesis examined which of nine EF variables contributed significant unique variance in three tests of ToM. Three separate regression analyses were conducted and the pattern of EF domains associated with ToM performance differed for each test. In total, cognitive flexibility, verbal fluency, design fluency, problem solving, and deductive reasoning accounted for a significant and unique amount of variance in the ToM tests. However, each tests yielded a different EF pattern.

Index words: Executive Function, Theory of Mind

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

The purpose of this study was to determine which aspects of Executive Function (EF) are related to the construct of Theory of Mind (ToM). EF consists of higher-order cognitive processes (Carlson, Mandell, & Williams, 2004) involved in goal-oriented behavior, such as planning and sequencing (Royall et al., 2002). ToM refers to the ability to understand the views and beliefs of another person (Baron-Cohen, 1988). This definition of ToM (Baron-Cohen, 1988) exemplifies how complex and abstract the nature of perspective-taking is, and therefore it can benefit from further operationalism. Determining the absolute presence of ToM does not explain the underlying mechanisms; but, by searching for its relationship with EF, we can identify the processes behind ToM that yield a better understanding of it. For example, conceptualizing ToM as driven solely by inhibition is different than if it is found to be driven by inhibition *and* planning.

Theory of Mind

The concept of ToM originated from Premack and Woodruff's research on the ability of chimpanzees to take the perspective of a person (1978). As stated earlier, ToM refers to the ability to understand the views and beliefs of another person (Baron-Cohen, 1988). Traditionally, ToM has been measured in false belief paradigms. For example, the common Sally-and-Anne test involves a scenario in which one character hides an object while another character leaves the room. Participants are then asked where they think the character who left the room will look for the object. Perspective-taking capabilities are required in order for participants to recognize that the character who has left the room does not know that the object was moved and therefore will look for the object in the original location (Brüne & Brüne-Cohrs, 2005). ToM is considered to consist of more than simple emotion recognition, as it involves inferring not only the emotions of another individual, but his or her beliefs as well. Therefore, ToM is considered a cognitive construct rather than an affective one (Baron-Cohen, 1988).

ToM development occurs across several stages (for a review, see Brüne and Brüne-Cohrs, 2005). The first stage is believed to occur at 1 year of age, at which point joint attention develops. Joint attention refers to the ability to comprehend the relationship between one's own and another's perception of objects. Next, this understanding is extended toward mood and goal, which occurs between 14 to 18 months. De-coupling, which is best exemplified through pretend play, refers to the ability to separate imaginal and real-life events. This begins at 18 to 24 months. According to Brüne and Brüne-Cohrs (2005), false belief (comprehension that another's person's belief can be different from one's own) occurs at 3 to 4 years of age, though this is not without some controversy (e.g., see Cutting & Dunn, 1999; Moses & Flavell, 1990). The next stage of ToM development is the comprehension of irony, which occurs at 6 to 7 years. Finally, between 9 and 11 years of age, children are postulated to understand faux pas. A faux pas occurs when one person inadvertently makes a comment that offends another person. Therefore, the understanding of faux pas requires ToM comprehension of more than one persona at a time (Brüne & Brüne-Cohrs, 2005).

If one lacks adequate ToM skills, it is apparent that this would affect one's everyday functioning. Much of life uses social interaction. From school, work, and peer and intimate relationships, perspective-taking is paramount. This makes ToM an important area of study. Furthermore, ToM is an important area of research because of its deficiency in some clinical populations. For example, individuals with Autism Spectrum Disorders have poor ToM skills (Baron-Cohen, Leslie, & Frith, 1985, Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997; Happé, 1994; Kaland et al., 2002; Gottlieb, 2005). Furthermore, ToM deficits have been shown in people with dementia and bipolar disorder (Brüne & Brüne-Cohrs, 2005; Bora et al., 2005; Cuerva et al, 2001; Gregory et al, 2002; Kerr, Dunbar, & Benteall, 2003).

Multiple ToM measures have been developed and have largely been assumed to be highly correlated with one another. For example, when ToM measures have been used, they generally have been aggregated into a single domain score (Salztman et al, 2000; Fahie & Symons, 2003; Yirmiya et al., 1998). While it has been difficult to identify studies that have looked at the variance among ToM (Milders, Fuchs, & Crawford, 2003; Shaw et al., 2004; Solomon, Goodlin-Jones, & Anders, 2004), some studies should be noted for their effort in doing so. In Muris et al. (1999), the authors found that several tests of ToM were significantly correlated with one another. Joseph and Tager-Flusberg's study (2004), which administered three different ToM tasks, reported a Chronbach's alpha of 0.90. Gregory et al. (2002) also reported good correlations among the Faux Pas test and two other basic tests of ToM. Ozonoff, Pennington, and Rogers (1991) used several ToM tests and compiled them into first-order and second-order composite scores. Although they did not individually correlate all measures, they still correlated the two composite scores, which were shown to have a correlation of 0.44 in normal controls. Gordon and Olsen (1998) also noted significant correlations among the ToM tests used in their study. The relative rareness of reported ToM correlations is potentially problematic and should be studied.

Executive Function

EF refers to higher-order cognitive processes required for individuals to complete goal-driven tasks (Lezak, Howieson, & Loring, 2004). The prefrontal cortex may control EF, because of its ability to incorporate multiple types of information needed for a task (Royall et al., 2002). However, there is still no agreement of what constitutes all of the components of EF, and many models exist to explain EF domains (for a review, see Stuss & Knight, 2002).

Lezak et al. (2004) postulated that EF consisted of four stepwise domains: Volition, Planning, Purposive Action, and Effective Performance. From formulation of a plan (Volition) to choosing the appropriate steps (Planning) to execution (Purposive Action) to evaluation (Effective Performace), Lezak et al. stated that these steps constituted EF. In an effort to identify EF components, Busch, McBride, Curtiss, and Vanderploeg (2005) examined 104 participants with traumatic brain injury. Using factor analysis, they found that cognitive flexibility and fluency, inhibition, and working memory explained 52.7% of the variance of performance on several traditional EF measures. The Cognitive-Process approach avoids separating out distinct domains of EF and focuses on the skills necessary to complete tradition EF tests (Homack, Lee, & Riccio, 2005; Delis, Kaplan, & Kramer, 2001). However, although there is discrepancy on defining the exact components of EF, all models agree that EF constitutes the steps necessary to solve a complex task (Zelzao & Frye, 1998). For the purposes of this study, the main executive components outlined in the Cognitive Process approach of the Delis-Kaplan Executive Function System (D-KEFS) were used as EF domains. They are: (1) cognitive flexibility, (2) verbal fluency, (3) design fluency, (4) inhibition, (5) problem solving, (6) categorical processing, (7) deductive reasoning, (8) spatial planning, and (9) verbal abstraction. Cognitive flexibility is postulated as the capacity to adapt to new rules. Verbal and design fluency constitute the ability to quickly make unique designs or words. Inhibition requires one to stop a prepotent response. Problem solving refers to the capacity to successfully solve a problem. In categorical processing, one has to be able to systematically organize information. In order to have adequate deductive reasoning skills, one has to be able to use clues in order to solve a puzzle. Verbal abstraction refers to the capacity to not literally comprehend all statements (Delis et al., 2001).

Executive Function and Theory of Mind

Previous studies have examined the EF-ToM relationship, and results have been variable. A case study of an adult who sustained amygdala damage and was diagnosed with both Asperger's Disorder and Schizophrenia found EF deficits but normal ToM functioning (Fine, Lumsden, & Blair, 2001). Another case study of an adult with impaired orbitofrontal ability also reported no relationship between EF and ToM (Bach, Happé, Fleminger, & Powell, 2005).

However, other studies have determined a relationship between EF and ToM. In a review, Hughes and Graham concluded that in addition to EF and ToM deficits in Autism Spectrum Disorders, the two domains are related to one another (2002). In a study of children with Autism, it was found that performance on ToM was significantly and positively related to working memory and inhibition (Joseph & Tager-Flusberg, 2004). Fisher and Happé (2005) trained two groups of children in ToM skills or EF skills and found that better performance in EF skills was positively associated with better performance in ToM. Thus, it seems that in the Autism Spectrum Disorders, there may be an association between EF and ToM.

This EF-ToM association has also been found outside of Autism Spectrum Disorders. In children with attentional and behavioral problems, ToM and working memory were found to be significantly and positively related (Fahie & Symons, 2003). In a sample of "hard to manage" preschoolers, Hughes, Dunn, and White found that EF and ToM were positively correlated

(1998). This relationship has been found in normal populations as well. In a study of normal preschoolers by Gordon and Olsen, results indicated better ToM performance as a function of better performance of EF (1998). Cole and Mitchell found similar conclusions in 119 3-5-year-old children (2000). A longitudinal study by Hughes (1998) demonstrated that EF predicted ToM performance over time, but ToM did not predict EF. Not only has the EF-ToM relationship been found outside of the Autism Spectrum Disorders, but it is also seen in other cultures. In a study that examined preschoolers from China and the United States, researchers found that planning, cognitive flexibility, and inhibition were positively correlated with ToM (Sabbagh, Xu, Carlson, Moses, & Lee, 2006). This EF-ToM relationship is not specific to children, either. Saltzman, Strauss, Hunter, and Archibald found that design fluency, problem solving, and verbal fluency were positively correlated with ToM in an elder population (2000). Finally, Carlson et al. (2004) found that this relationship between EF and ToM appears to emerge at 39 months and found that inhibition and working memory were related to ToM.

Several EF domains have been examined in previous studies to determine the EF-ToM relationship, but which EF domains share the most variance with ToM? Thus far, there have been few studies that have attempted to answer this question. Carlson, Moses and Breton found that inhibition had a causal association with ToM over working memory (2002). Following this study, researchers found that inhibition was a stronger predictor of ToM over planning (Carlson, Moses, & Claxton, 2004). The significance of inhibitory skills with adequate ToM abilities is a sensible argument, as one needs to be able to inhibit prepotent responses that may be socially inappropriate.

There has been promising research into the specific relationship between EF and ToM. However, most of these studies examined children (Fisher & Happé, 2005; Joseph & Tager-

Flusberg, 2004; Fahie & Symons, 2003; Cole & Mitchell, 2000; Sabbagh, Xu, Carlson et al., 2006; Carlson et al., 2002; Carlson et al., 2004; Carlson et al., 2004). The limitation of this is that children are still developing ToM (Brüne & Brüne-Cohrs, 2005). Therefore, it becomes difficult to conclude if EF and ToM are actually related as the participants are still developing. Additionally, EF is not fully developed until after childhood (Anderson, Levin, & Jacobs, 2002). To avoid these problems, this study used a sample of normal adults because they *should* have fully developed their ToM abilities (Brüne & Brüne-Cohrs, 2005). This means that the question of how far along a participant is in development does not confound the results to the same degree as with a child population.

Importantly, there has not been a comprehensive study that examines the relationship among as many aspects (as defined by Delis, Kaplan, & Kramer, 2001) of EF possible and ToM. Previous studies only compared a limited number of EF domains (such as inhibition and working memory) with a limited number of tests of ToM (Carlson et al., 2002; Carlson et al., 2004; Carlson et al., 2004). For this reason, we used the D-KEFS, a comprehensive battery of EF (Delis et al., 2001).

Aim

The aim of this study was to identify which domains of EF are the best predictors of ToM, as obtained from a normal adult population. The D-KEFS was used because of its atheoretical approach to EF (Homack et al., 2005), and its representation of a comprehensive set of EF measures (Delis et al.2001).

Before using multiple ToM measures to address the aim of this study, it was important to determine whether the ToM tests used were related to one another, as they theoretically should be. Three tests of ToM were used in this study: the Reading the Mind in the Eyes (RMET) test, Strange Stories test, and Faux Pas test. Each of these tests measures different aspects of ToM, (Baron-Cohen et al., 2001; Happé, 1994; Stone, Baron-Cohen, & Knight, 1998; Gregory et al., 2002). A pilot study was conducted to investigate the concordance among three ToM tasks. Twenty participants were administered these tests. A Pearson correlation matrix was conducted, and none of the ToM tests were significantly correlated (all p's < 0.05) (Ahmed, Miller, & Abner). While these tests are assumed to measure different aspects of ToM (i.e., emotion recognition, general inference of others' mental states, and faux pas) (Baron-Cohen et al., 2001; Happé, 1994; Stone, Baron-Cohen, & Knight et al., 1998; Gregory et al., 2002), theoretically, they should be at least moderately correlated (as Ozonoff et al. (1991) reported concordance among first- and second-order ToM composites), as they each purport to measure ToM. The absence of a significant correlation in this small sample indicates that the ToM tests may actually measure different constructs. Therefore, it was important to examine the correlations among these three ToM tests in the current study before analyzing the results.

CHAPTER 2

METHODS

Participants

135 research participants were recruited from the University of Georgia Research Participant Pool were in this study. Participants ranged in age between 18 and 27 years (*M* = 19.04, *SD* = 1.3) and were excluded from the study based on the presence of ongoing psychosis, depression, current psychiatric medication, and/or poor effort. To screen out for psychosis, the Psychotic Screen from the Structured Clinical Interview for DSM-IV Axis I Disorders (First, Spitzer, Gibbon, & Williams, 1996) was used as a measure of gross psychological impairment. Endorsement of any of these items (e.g., visual or auditory hallucinations, persecutory or grandiose delusions, etc.) excluded the participant's data from this study. To screen for depression, participants were administered the Beck Depression Inventory (BDI) (The Psychological Corporation, 1996). This is a 21-item questionnaire in which the participants rate statements about their mood from 0 to 3, with 0 representing the absence of the mood. The statements are restricted to how the participant has been feeling during the past two weeks (e.g., sadness, loss of pleasure, irritability, and worthlessness). Data from participants who obtained a BDI score of 20 (i.e., moderate depression) or more were excluded from the study. The Medical Symptom Validity Test (MSVT) was administered to screen for poor effort. This is an empirically-supported, quantitative measure of effort that requires participants to recall words in a forced-choice format (Richman et al., 2006; Merten et al., 2005). As a result, five participants

were excluded for current psychotic symptoms, three for depression, four for current psychiatric medication use, and none for poor effort, leading to a final N of 123.

Procedure

This study was conducted in a single session in the Neuropsychology and Memory Assessment Laboratory at the University of Georgia. Informed consent was obtained by a written form approved by the university Institutional Review Board. All participants also received verbal explanation of their rights as well as received course credit.

First, demographic information was obtained. Participants were also administered the Wechsler Test of Adult Reading (WTAR) in order to obtain a predicted Full Scale IQ (FSIQ) score (The Psychological Corporation, 2001).

Next, the participants were administered the D-KEFS and three ToM tests (RMET, Strange Stories Test, and Faux Pas Test). The order of these tests (EF battery first or ToM battery first) were counterbalanced. The order of the ToM tests were as follows: Reading the Mind in the Eyes test, Strange Stories test, and Faux Pas test. The Strange Stories test included six randomized sets that were cycled through every six participants. Tests were administered and scored according to standard protocol (Baron-Cohen et al., 2001; Delis, et al., 2001; Gregory et al, 2002; Happé, 1994; Stone, Baron-Cohen, & Knight, 1998).

After the completion of testing, participants received a written and verbal debriefing of the study's aims.

Measures

<u>Delis-Kaplan Executive Function System</u>

The Delis-Kaplan Executive Function System (D-KEFS) is a battery of nine subtests that measure EF. This battery is based on several traditional neuropsychological tests that have been updated and normed on the same sample. This is the first battery of EF tests that has been normed on such a large sample (1,750 adults and children) and yields an age range of 8-89 years. Each of the nine subtests ((1) Word Context Test, (2) Sorting Test, (3) Twenty Questions Test, (4) Tower Test, (5) Color-Word Interference, (6) Verbal Fluency Test, (7) Design Fluency Test, (8) Trail Making Test, and (9) Proverb Test) yield multiple scores; however we pulled one EF domain score from each test. They are: (1) cognitive flexibility, (2) verbal fluency, (3) design fluency, (4) inhibition, (5) problem solving, (6) categorical processing, (7) deductive reasoning, (8) spatial planning, and (9) verbal abstraction (Delis et al., 2001).

Because of the large age range of the D-KEFS, it has low floors and high ceilings. Furthermore, there is moderate reliability and validity. Test-retest reliability across subtests is between 0.06 to 0.90. The internal consistency across subtests is between 0.33 and 0.90. In terms of validity, the D-KEFS reports internal consistency between -0.94 to 0.95 (Delis et al., 2001).

The D-KEFS tests were administered and scored according to standard protocol (Delis et al., 2001).

Reading the Mind in the Eyes Test

A foundational ability needed for ToM is emotion recognition. The Reading the Mind in the Eyes Test (RMET) is one such test of emotion recognition and is considered a test of ToM. A strength of the RMET is its ability to determine difficulties in ToM from high-functioning individuals with Autism Spectrum Disorders (Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997). This is a 36-item multiple-choice test in which participants are asked to identify the emotion portrayed by various actors' eyes. A glossary of the multiple-choice answers is also provided in case participants do not know the definition of all of the answer choices (Baron-Cohen et al., 2001).

This study used the revised version of the test, which has better psychometric qualities than the original version, having removed the ceiling effect found in normal controls on the original version. Therefore, it is better able to differentiate from high-functioning Autistic participants and normal controls compared to the original.

The RMET was validated on the Autism Quotient, which measures Autistic symptoms (Baron-Cohen et al., 2001). Since individuals with Autism Spectrum Disorders perform poorly on ToM tests (Baron-Cohen, Leslie, & Frith, 1985, Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997; Happé, 1994; Kaland et al., 2002; Gottlieb, 2005), scores on the RMET should be inversely correlated with scores from the Autism Quotient. This was seen with the RMET ($r = -.53$, $p < .01$) (Baron-Cohen et al., 2001). Finally, since this study used a normal college-aged population, it was important that the ToM test be designed for normal adults. The revised version of the RMET can be used to assess a normal population (Baron-Cohen et al., 2001).

The RMET was administered and scored according to standard protocol (Baron-Cohen et al., 2001).

Strange Stories Test

The Strange Stories test (Happé, 1994) was designed to be a more sophisticated measure of ToM abilities, as traditional ToM tests tended to measure only first-order ToM abilities, usually in a false belief paradigm. However, it was still possible for individuals to pass these gross measures of ToM and yet still struggle with perspective-taking. Therefore, the Strange Stories test was designed as an “advanced” test. It consists of vignettes in which the participant has to identify the reason for the behavior of the character in each story. The ToM concepts that are tapped by this test are areas such as white lies and double bluffs (Happé, 1994; Jolliffe & Baron-Cohen, 1999).

Happé found that children with Asperger's Disorder perform poorly on the vignettes that require ToM ability (1994), thus making this a good subtle measure of ToM. Interrater reliability of the Strange Stories test has been reported at 87% (Happé, Winner, & Brownell, 1998). Additionally, the Strange Stories test has been well-vallidated, as it has been able to show differences among individuals from the Autism Spectrum Disorders (Happé, 1994; Kaland et al., 2002; Gottlieb, 2005).

The Strange Stories test is not limited to children, as there is also a different version for adults that has also been found to be a sensitive ToM measure (Happé, 1994; Jolliffe & Baron-Cohen, 1999; Happé, Winner, & Brownell, 1998; Maylor, Moulson, Muncer, & Taylor, 2002; . Sullivan, & Ruffman, 2004). For the present study, another revised Strange Stories test was used with permission from the test developer which consists of 16 items, half of which are control vignettes and half of which require ToM ability.

Administration of the Strange Stories test adhered to the standard protocol which consisted of reading the vignettes aloud to the participants while the participants were provided with a written version of the vignettes as well (Happé, 1994). However, for nine participants, materials were presented in written form only. An independent samples t-test used to determine whether there were any group differences indicated no significant group differences. The majority of the Strange Stories tests were scored by two undergraduate raters, and interrater reliability was established ($\rho = .87, p < .01$). Therefore, a composite variable was calculated. The remainder of the tests were scored by the first author, and interrater reliability was established among the first author and the two raters from a subset of the data ($\rho = 0.89, \rho = 0.89, p < .01$). This yielded a variable that consisted of either the average score of the two raters or the sole score rated by the first author.

Faux Pas Test

A faux pas is defined as an act in which a person makes an inappropriate comment without intending for the negative impact it has on another person. It is considered a very well-developed form of ToM, as one needs to simultaneously take the perspective of two different people (Brüne & Brüne-Cohrs, 2005; Gregory et al, 2002; Stone, Baron-Cohen, & Knight, 1998). The Faux Pas test measures a person's ability to detect whether a faux pas has occurred through a series of vignettes. Participants are read a series of 20 vignettes, 10 of which contain a faux pas. The participant has to identify that a faux pas occurred, that it resulted in a negative emotion in the other individual, and that the person making the faux pas did not intend for the negative emotion (Gregory et al., 2002; Stone, Baron-Cohen, & Knight, 1998).

Good psychometric properties exist for this test. The Faux Pas test was shown to have good interrater reliability at 0.98 and correlated well with a first- and second-order measure of ToM (r = .76 and 0.78, $p < .05$). It did not correlate significantly with the RMET (Gregory et al., 2002).

Administration of the Faux Pas test adhered to the standard protocol which consisted of reading the vignettes aloud to the participants while the participants were provided with a written version of the vignettes as well (Gregory et al., 2002; Stone, Baron-Cohen, & Knight, 1998). However, for nine participants, materials were presented in written form only. An independent samples t-test used to determine whether there were any group differences indicated no significant group differences. The majority of the Faux Pas tests were scored by two undergraduate raters, and interrater reliability was established ($\rho = 0.91$, $p < .01$). Therefore a composite variable was calculated. The remainder of the tests were scored by the first author, and interrater reliability was established among the first author and the two raters from a subset of the data ($\rho = 0.96$, $\rho = 0.89$, $p < .01$). This yielded a variable that consisted of either the average score of the two raters or the sole score rated by the first author.

Variables

For the ToM tests, the total number correct from the RMET was one variable, the total score of the Strange Stories test was another variable, and the total score from the Faux Pas test was the third variable. The ToM scores were not aggregated, as they were not significantly correlated with one another (Ahmed, Miller, & Abner, 2007).

Each of the nine EF domains, (1) cognitive flexibility, (2) verbal fluency, (3) design fluency, (4) inhibition, (5) problem solving, (6) categorical processing, (7) deductive reasoning, (8) spatial planning, and (9) verbal abstraction, were predictor variables. The scaled score from Condition 4 of the Trail-Making Test referred to cognitive flexibility. The scaled score from the Letter Fluency condition of the Verbal Fluency Test indicated verbal fluency. Design fluency was represented by the scaled score from Condition 1 of the Design Fluency Test. The scaled score from Condition 3 of the Color-Word Interference Test designated inhibition. Problem solving was indicated by the scaled score from the confirmed correct sorts of the Free Sort condition of the Sorting Test. The scaled score from the total weighted achievement of the Twenty Questions Test represented categorical processing. Deductive reasoning was indicated by the scaled score from the total number of consecutively correct of the Word Context Test. The total achievement scaled score of the Tower Test represented spatial planning. Finally, the cumulative percentile rank from the Multiple Choice condition of the Proverb Test indicated verbal abstraction (Delis et al., 2001).

Analysis of Data

Because the ToM variables were not significantly correlated (Ahmed, Miller, & Abner, 2007), three separate regression analyses were conducted. The nine variables from the D-KEFS scores were entered as the predictor variables and each of the three ToM scores were the dependent variables for each regression. Spearman correlations were calculated to analyze the variance among the ToM tests.

CHAPTER 3

EXECUTIVE FUNCTION MECHANISMS OF THEORY OF MIND[1]

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Abstract

The relationship between Executive Function (EF) and Theory of Mind (ToM) are examined in this study. Using the Delis-Kaplan Executive Function System (D-KEFS) and three tests of ToM (the Reading the Mind in the Eyes test, Strange Stories test, and Faux Pas test), the authors explored whether EF accounted for a significant amount of variance in ToM performance and, if so, which domains shared most of the variance. Three separate regression analyses were conducted and the pattern of EF domains associated with ToM performance differed for each test. In total, cognitive flexibility, verbal fluency, design fluency, problem solving, and deductive reasoning accounted for a significant and unique amount of variance in the ToM tests. However, each tests yielded different EF patterns.

Executive Function Mechanisms of Theory of Mind

Introduction

The purpose of this study was to determine which aspects of Executive Function (EF) are related to the construct of Theory of Mind (ToM). EF consists of higher-order cognitive processes (Carlson, Mandell, & Williams, 2004) involved in goal-oriented behavior, such as planning and sequencing (Royall et al., 2002). ToM refers to the ability to understand the views and beliefs of another person (Baron-Cohen, 1988). This definition of ToM (Baron-Cohen, 1988) exemplifies how complex and abstract the nature of perspective-taking is, and therefore it can benefit from further operationalism. Determining the absolute presence of ToM does not explain the underlying mechanisms; but, by searching for its relationship with EF, we can identify the processes behind ToM that yield a better understanding of it. Previous research has indicated that there may be multiple domains of ToM (Ahmed, Abner, & Miller, 2007, February; Ahmed & Miller, unpublished), and thus there may be differing EF mechanisms that drive each type of ToM. For example, conceptualizing ToM as being driven solely by inhibition is different than if it is found to be driven by inhibition *and* planning.

Theory of Mind

The concept of ToM originated from Premack and Woodruff's research on the ability of chimpanzees to take the perspective of a person (1978). As stated earlier, ToM refers to the ability to understand the views and beliefs of another person (Baron-Cohen, 1988). Traditionally, ToM has been measured in false belief paradigms. For example, the common Sally-and-Anne test involves a scenario in which one character hides an object while another character leaves the room. Participants are then asked where they think the character who left the room will look for the object. Perspective-taking capabilities are required in order for participants to recognize that the character who has left the room does not know that the object was moved and therefore will look for the object in the original location (Brüne & Brüne-Cohrs, 2005). Several tests of ToM exist in the extant literature, and often times studies will calculate an aggregate ToM score during the analysis (Salztman et al, 2000; Fahie & Symons, 2003; Yirmiya et al., 1998). ToM is considered to consist of more than simple emotion recognition, as it involves inferring not only the emotions of another individual, but his or her beliefs as well. Therefore, ToM is considered a cognitive construct rather than an affective one (Baron-Cohen, 1988).

ToM development occurs across several stages (for a review, see Brüne and Brüne-Cohrs, 2005). The first stage is believed to occur at 1 year of age, at which time joint attention is developed. Joint attention refers to the ability to comprehend the relationship between another's perception of an object. Next, this understanding is extended toward mood and goal, which occurs between 14 to 18 months. De-coupling, which is best exemplified through pretend play, refers to the ability to separate imaginal and real-life events. This begins at 18 to 24 months. According to Brüne and Brüne-Cohrs (2005), false belief (comprehension that another's person's belief can be different from one's own) has been reported to occur at 3 to 4 years of age, though this is not without some controversy (e.g., see Cutting & Dunn, 1999; Moses & Flavell, 1990). The next stage of ToM development is the comprehension of irony, which occurs at 6 to 7 years. Finally, between 9 and 11 years of age, children are postulated to understand faux pas. A faux pas occurs when one person inadvertently makes a comment that offends another person. Therefore, understanding of faux pas requires ToM comprehension of more than one persona at a time (Brüne & Brüne-Cohrs, 2005).

If one lacks adequate ToM skills, it is apparent that this would affect one's everyday functioning. Much of life uses social interaction. From school, work, and peer and intimate relationships, perspective-taking is paramount. This makes ToM an important area of study. Furthermore, ToM is an important area of research because of its deficiency in some clinical populations. For example, individuals with Autism spectrum disorders have poor ToM skills (Baron-Cohen, Leslie, & Frith, 1985, Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997; Happé, 1994; Kaland et al., 2002; Gottlieb, 2005). Furthermore, ToM deficits have been shown in people with dementia and bipolar disorder (Brüne & Brüne-Cohrs, 2005; Bora et al., 2005; Cuerva et al, 2001; Gregory et al, 2002; Kerr, Dunbar, & Benteall, 2003).

Executive Function

EF refers to higher-order cognitive processes required for individuals to complete goal driven tasks (Lezak, Howieson, & Loring, 2004). The prefrontal cortex may control EF, because of its ability to incorporate multiple types of information needed for a task (Royall et al., 2002). However, there is still no agreement of what constitutes all of the components of EF, and many models exist to explain EF domains (for a review, see Stuss & Knight, 2002).

Lezak et al. (2004) postulated that EF consisted of four stepwise domains: Volition, Planning, Purposive Action, and Effective Performance. From formulation of a plan (Volition) to choosing the appropriate steps (Planning) to execution (Purposive Action) to evaluation (Effective Performace), Lezak et al. stated that these steps constituted EF. In an effort to identify EF components, Busch, McBride, Curtiss, and Vanderploeg (2005) examined 104 participants with traumatic brain injury. Using factor analysis, they found that cognitive flexibility and fluency, inhibition, and working memory explained 52.7% of the variance of performance on several traditional EF measures. The Cognitive-Process approach avoids separating out distinct domains of EF and focuses on the skills necessary to complete tradition EF tests (Homack, Lee, & Riccio, 2005; Delis, Kaplan, & Kramer, 2001). However, although there is discrepancy on defining the exact components of EF, all models agree that EF constitutes the steps necessary to solve a complex task (Zelzao & Frye, 1998). For the purposes of this study, the main executive components outlined in the Cognitive Process approach of the Delis-Kaplan Executive Function System were used as EF domains. They are: (1) cognitive flexibility, (2) verbal fluency, (3) design fluency, (4) inhibition, (5) problem solving, (6) categorical processing, (7) deductive reasoning, (8) spatial planning, and (9) verbal abstraction. Cognitive flexibility is postulated as the capacity to adapt to new rules. Verbal and design fluency constitute the ability to quickly make unique designs or words. Inhibition requires one to stop a prepotent response. Problem solving refers to the capacity to successfully solve a problem. In categorical processing, one has to be able to systematically organize information. In order to have adequate deductive reasoning skills, one has to be able to use clues in order to solve a puzzle. Verbal abstraction refers to the capacity to not literally comprehend all statements (Delis et al., 2001).

Executive Function and Theory of Mind

Previous studies have examined the EF-ToM relationship, and results have been variable. A case study of an adult who sustained amygdala damage and was diagnosed with both Asperger's Disorder and schizophrenia found EF deficits but normal ToM functioning (Fine, Lumsden, & Blair, 2001). Another case study of an adult with impaired orbitofrontal capacity also reported no relationship between EF and ToM (Bach, Happé, Fleminger, & Powell, 2005).

However, other studies have determined a relationship between EF and ToM. In a review, Hughes and Graham concluded that in addition to EF and ToM deficits in Autism Spectrum Disorders, the two domains are related to one another (2002). In a study of children with Autism, it was found that performance on ToM was significantly and positively related to working memory and inhibition (Joseph & Tager-Flusberg, 2004). Fisher and Happé (2005) trained two groups of children in ToM skills or EF skills and found that better performance in EF skills was positively associated with better performance in ToM. Thus, it seems that in the Autism Spectrum Disorders, there may be an association between EF and ToM.

This EF-ToM association has also been found outside of Autism Spectrum Disorders. In children with attentional and behavioral problems, ToM and working memory were found to be significantly and positively related (Fahie & Symons, 2003). In a sample of "hard to manage" preschoolers, Hughes, Dunn, and White found that EF and ToM were positively correlated (1998). This relationship has been found in normal populations as well. In a study of normal preschoolers by Gordon and Olsen, results indicated better ToM performance as a function of better performance of EF (1998). Cole and Mitchell found similar conclusions in 119 3-5-year-old children (2000). A longitudinal study by Hughes (1998) demonstrated that EF predicted ToM performance over time, but ToM did not predict EF. Not only has the EF-ToM relationship been found outside of the Autism Spectrum Disorders, but it is also seen in other cultures. In a study that examined preschoolers from China and the United States, researchers found that planning, cognitive flexibility, and inhibition were positively correlated with ToM (Sabbagh, Xu, Carlson, Moses, & Lee, 2006). This EF-ToM relationship is not specific to children, either. Saltzman, Strauss, Hunter, and Archibald found that design fluency, problem solving, and verbal fluency were positively correlated with ToM in an elder population (2000). Finally, Carlson et al. (2004) have found that this relationship between EF and ToM appears to emerge at 39 months and found that inhibition and working memory were related to ToM.

Several EF domains have been examined in previous studies to determine the EF-ToM relationship, but which EF domains share the most variance with ToM? Thus far, there have been few studies that have attempted to answer this question. Carlson, Moses and Breton found that inhibition had a causal association with ToM over working memory (2002). Following this study, researchers found that inhibition was a stronger predictor of ToM over planning (Carlson, Moses, & Claxton, 2004). The significance of inhibitory skills with adequate ToM abilities is a sensible argument, as one needs to be able to inhibit prepotent responses that may be socially inappropriate.

There has been promising research into the specific relationship between EF and ToM. However, most of these studies examined children (Fisher & Happé, 2005; Joseph & Tager-Flusberg, 2004; Fahie & Symons, 2003; Cole & Mitchell, 2000; Sabbagh, Xu, Carlson et al., 2006; Carlson et al., 2002; Carlson et al., 2004; Carlson et al., 2004). The limitation of this is that children are still developing ToM (Brüne & Brüne-Cohrs, 2005). Therefore, it becomes difficult to conclude if EF and ToM are actually related because the participants are still developing. Additionally, EF is not fully developed until after childhood (Anderson, Levin, & Jacobs, 2002). To avoid these problems, this study used a sample of normal adults because they *should* have fully developed their ToM abilities (Brüne & Brüne-Cohrs, 2005). This means that the question of how far along a participant is in development does not confound the results to the same degree as with a child population.

Importantly, there has not been a comprehensive study that examines the relationship among as many aspects (as defined by Delis, Kaplan, & Kramer, 2001) of EF possible and ToM. Previous studies only compared a limited number of EF domains (such as inhibition and working memory) with a limited number of tests of ToM (Carlson et al., 2002; Carlson et al., 2004; Carlson et al., 2004). For this reason, we used the D-KEFS, a comprehensive battery of EF (Delis et al., 2001).

Aim

The aim of this study was to identify which domains of EF are the best predictors of ToM, as obtained from a normal adult population. The D-KEFS was used because of its atheoretical approach to EF (Homack et al., 2005), and its representation of a comprehensive set of EF measures (Delis et al.2001).

Methods

Participants

135 research participants from the University of Georgia Research Participation Pool participated in this study. Participants ranged in age between 18 to 27 years (M = 19.04, SD = 1.3) and were excluded from the study based on the presence of ongoing psychosis, depression, current psychiatric medication, or poor effort. To screen out for psychosis, the Psychotic Screen from the Structured Clinical Interview for DSM-IV Axis I Disorders (First, Spitzer, Gibbon, & Williams, 1996) was used as a measure of gross psychological impairment. Endorsement of any of these items (e.g., visual or auditory hallucinations, persecutory or grandiose delusions, etc.) excluded the participant's data from this study. To screen for depression, participants were administered the Beck Depression Inventory (BDI), which indicates current depressive symptoms. Moderate depression is indicated by a BDI score of 20 (The Psychological Corporation, 1996). Data from participants who obtain a BDI score of $\geq$ 20 (i.e., moderate depression) or more were excluded from the study. The Medical Symptom Validity Test (MSVT) was administered to screen for poor effort. This is an empirically-supported, quantitative measure of effort (Richman et al., 2006; Merten et al., 2005). Following exclusion criteria, the final participant N was 123.

Procedure

This study was conducted in a single session in the Neuropsychology and Memory Assessment Laboratory at the University of Georgia. Informed consent was obtained by a written form approved by the university Institutional Review Board. All participants also received verbal explanation of their rights as well as course credit.

First, demographic information was obtained. Participants were also administered the Wechsler Test of Adult Reading (WTAR) in order to obtain a predicted Full Scale IQ (FSIQ) score (The Psychological Corporation, 2001).

Next, participants were administered the D-KEFS and three ToM tests (Reading the Mind in the Eyes test (RMET), Strange Stories Test, and Faux Pas Test). The order of these tests (EF battery first or ToM battery first) were counterbalanced. The order of the ToM tests were as follows: RMET, Strange Stories test, and Faux Pas test. The Strange Stories test included six randomized sets that were cycled through every six participants. Tests were administered and scored according to standard protocol (Baron-Cohen et al., 2001; Delis, et al., 2001; Gregory et al, 2002; Happé, 1994 ; Stone, Baron-Cohen, & Knight, 1998).

After the completion of testing, participants received a written and verbal debriefing of the study's aims.

Measures

<u>Delis-Kaplan EF System</u>

The Delis-Kaplan Executive Function System (D-KEFS) is a battery of nine subtests that measure EF. This battery is based on several traditional neuropsychological tests that have been updated and normed on the same sample. This is the first battery of EF tests that has been normed on such a large sample (1,750 adults and children) and yields an age range of 8-89 years.

Each of the nine subtests ((1) Word Context Test, (2) Sorting Test, (3) Twenty Questions Test, (4) Tower Test, (5) Color-Word Interference, (6) Verbal Fluency Test, (7) Design Fluency Test, (8) Trail Making Test, and (9) Proverb Test) yield multiple scores; however one EF domain score can be pulled from each test. They are: (1) cognitive flexibility, (2) verbal fluency, (3) design fluency, (4) inhibition, (5) problem solving, (6) categorical processing, (7) deductive reasoning, (8) spatial planning, and (9) verbal abstraction (Delis et al., 2001).

Because of the large age range of the D-KEFS, it has low floors and high ceilings. Furthermore, there is moderate reliability and validity. Test-retest reliability across subtests is between 0.06 to 0.90. The internal consistency across subtests is beteen 0.33 and 0.90. In terms of validity, the D-KEFS reports internal consistency between -0.94 to 0.95 (Delis et al., 2001).

The D-KEFS tests were administered and scored according to standard protocol (Delis et al., 2001).

<u>Reading the Mind in the Eyes Test</u>

The Reading the Mind in the Eyes Test (RMET) has been developed as a subtle measure of ToM assessesing the fundamental skill needed for ToM: emotion recognition. The RMET has been show to identify ToM deficits in both healthy controls and individuals with high-functioning Autism and Asperger's Disorder (Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997). This test is made up of 36 photos of actors' eyes and requires the participant to identify the emotion that the actor is portraying (Baron-Cohen et al., 2001). An example is seen in Figure 3.1.

This study used the revised version of the test, as it has been shown to have better psychometric qualities than the original version, primarily in reducing normal performance to below ceiling compared to the original. Validity has been good. Scores on the Autism Quotient and the RMET were inversely correlated ($r = -0.53$, $p < 0.01$), with increasing severity of Autism associated with poorer scores on the RMET (Baron-Cohen et al., 2001). As previously noted, the amount of literature regarding variance among ToM measures is limited. However, the original version of the RMET was shown not to be correlated with three other tests of ToM in one study (Gregory et al., 2002).

Strange Stories Test

The Strange Stories test is another subtle test of ToM (Happé, 1994; Jolliffe & Baron-Cohen, 1999). It is purported to be an "advanced" test because of its sensitivity in detecting ToM deficits in individuals who generally pass traditional, gross measures (Happé, 1994). This test asseses more advanced concepts such as double bluff, white lies, and persuasion. Participants are presented with a series of vignettes and are asked to explain why the main character acted in a particular manner. An example of a ToM story is depicted in Figure 3.2.

A revised shorter version has also been found to be a sensitive measure of ToM in adults (Happé, 1994; Jolliffe & Baron-Cohen, 1999; Happé, Winner, & Brownell, 1998; Maylor, Moulson, Muncer, & Taylor, 2002; Sullivan, & Ruffman, 2004). A different revised version was used in this study (with permission from the test developer) which contains 16 items (8 control and 8 experimental) and developed specifically for younger and older participants.

The Strange Stories test has been found to have strong interrater reliability (87%) (Happé et al., 1998). Validity has also been good. Specifically, it has consistently shown poorer performance in participants with Autism Spectrum Disorders compared normal controls, thus demonstrating a deficient ToM ability in those with Autism Spectrum Disorders. Additionally, the Strange Stories test has been able to demonstrate subtle differences in test performance between severely autistic participants and higher-functioning Autistic participants (Happé, 1994; Kaland et al., 2002; Gottlieb, 2005).

Administration of the Strange Stories test adhered to the standard protocol which consisted of reading the vignettes aloud to the participants while the participants were provided with a written version of the vignettes as well (Happé, 1994). However, nine participants were given the stories to read themselves. An independent samples t-test used to determine whether there was any group differences indicated no significant group differences. The majority of the Strange Stories tests were scored by two undergraduate raters, and interrater reliability was established ($\rho = .87$, $p < .01$). Therefore, a composite variable was calculated. The remainder of the tests were scored by the first author, and interrater reliability was established among the first author and the two raters from a subset of the data ($\rho = .89$, $\rho = 0.89$, $p < .01$). This yielded a variable that consisted of either the average score of the two raters or the sole score rated by the first author.

Faux Pas Test

The Faux Pas test is another subtle measure of ToM. A faux pas is defined as an interaction in which one person inadvertently makes an inappropriate comment that results in negative feelings from the other person (Gregory et al., 2002; Stone, Baron-Cohen, & Knight, 1998). An example of a faux pas can be seen in Figure 3.3.

The Faux Pas test has been shown to have good interrater reliability. In terms of validity, it has good concordance with a first- and second-order ToM test, but not the RMET (Gregory et al., 2002). However, to the knowledge of the authors, concordance between the Faux Pas test and other ToM tests has not generally been reported in studies using this test (Shaw et al., 2004).

Administration of the Faux Pas test adhered to the standard protocol which consisted of reading the vignettes aloud to the participants while the participants were provided with a written version of the vignettes as well (Gregory et al, 2002; Stone et al., 1998). However, nine participants were given the stories to read themselves. An independent samples t-test used to determine whether there was any group differences indicated no significant group differences. The majority of the Faux Pas tests were scored by two undergraduate raters, and interrater reliability was established ($\rho = .91$, $p < .01$). Therefore a composite variable was calculated. The remainder of the tests were scored by the first author, and interrater reliability was established among the first author and the two raters from a subset of the data ($\rho = .96$, $\rho = .89$, $p < .01$). This yielded a variable that consisted of either the average score of the two raters or the sole score rated by the first author.

Variables

Before aggregating the three ToM tests into a single ToM variable as is common in the literature (Salztman et al, 2000; Fahie & Symons, 2003; Yirmiya et al., 1998), it was important to determine whether the three ToM tests were correlated. Furthermore, since the pilot study yielded no correlations (Ahmed, Miller, & Abner, 2007), it was important to examine whether this lack of correlations continued with a larger sample size.

For the ToM tests, the total number correct from the RMET was one variable, the total score of the Strange Stories test was another variable, and the total items correct from the Faux Pas test was a variable. Each of the nine EF domains, (1) cognitive flexibility, (2) verbal fluency, (3) design fluency, (4) inhibition, (5) problem solving, (6) categorical processing, (7) deductive reasoning, (8) spatial planning, and (9) verbal abstraction, were predictor variables. The scaled score from Condition 4 of the Trail-Making Test referred to cognitive flexibility. The scaled score from the Letter Fluency condition of the Verbal Fluency Test indicated verbal fluency. Design fluency was represented by the scaled score from Condition 1 of the Design Fluency Test. The scaled score from Condition 3 of the Color-Word Interference Test designated inhibition. Problem solving was indicated by the scaled score from the confirmed correct sorts of the Free Sort condition of the Sorting Test. The scaled score from the total weighted achievement of the Twenty Questions Test represented categorical processing. Deductive reasoning was indicated by the scaled score from the total number consecutively correct of the Word Context Test. The total achievement scaled score of the Tower Test represented spatial planning. Finally, the cumulative percentile rank from the Multiple Choice condition of the Proverb Test indicated verbal abstraction (Delis et al., 2001).

Results

Descriptives

Five participants were excluded from this study due to endorsing symptoms of current psychosis. Three participants were excluded due to the presence of depressive symptoms. The current use of psychiatric medication excluded four participants. No participants were excluded due to poor performance on the MSVT. The final number of participants included in this study was 123. Demographic information is summarized in Table 3.1. Descriptive data on the D-KEFS and ToM scores are summarized in Table 3.2.

Analyses

Correlational analyses were used to determine whether it was possible to aggregate the ToM tests. Rank-order correlations were conducted due to violations of normality in each ToM test, as each ToM test yielded a significant Kolmogorov-Smirnov statistic (all p's $< .01$). None of the three ToM tests were significantly correlated with each other (see Table 3.3).

Since the ToM tests were not correlated with one another, an aggregate ToM score was not calculated. Therefore, three separate regression analyses were conducted using the nine variables from the D-KEFS as predictor variables and each of the three variables from the ToM tests as single dependent variables. A correlational matrix was also calculated for the D-KEFS and ToM variables (see Table 3.4).

Before running the regression analyses, the amount of variance accounted for by demographic variables was examined. For the RMET, the WTAR-predicted FSIQ accounted for unique variance. No demographic variables were found to be significant with the Strange Stories test. For the Faux Pas test, age, gender, and years of education were found to be significant. In order to be able to compare across each of the three regression analyses, hierarchical regressions were conducted by simultaneously entering all four of these demographic variables into the first model and simultaneously entering the nine D-KEFS variables into the second model.

Regression 1: RMET

After entering in the demographic variables in the first model and the D-KEFS variables in the second model, a Cook's D analysis was employed in order to determine whether there were any outliers in the data set. Using a Cook's D value of 4/123 (0.0325), eight outliers were identified. After removing these eight participants from the data set, the regression analysis was re-entered. The overall model accounted for a significant amount of variance in RMET scores ($R^2 = 0.34$, $R^2 change = 0.13$, $F(13,101) = 4.00$, $p < .01$, see Table 3.5). Only cognitive flexibility ($\beta = -.25$, $t(101) = -2.59$, $p < .05$) accounted for significant variance in RMET performance. WTAR-predicted FSIQ still significantly accounted for variance in the RMET ($\beta = 0.36$, $t(101) = 3.81$, $p < .01$) in the overall model.

Regression 2: Strange Stories Test

As in the RMET regression, a Cook's D analysis was employed in order to determine whether there were any outliers in the data set. Using a Cook's D value of 4/123 (0.0325), nine outliers were identified. After removing these nine participants from the data set, the regression analysis was re-entered. The model accounted for a significant amount of variance in Strange Stories test scores ($R^2 = .278$, $R^2 change = .252$, $F\ (13,100) = 2.96$, $p < .01$, see Table 3.6). Verbal fluency ($\beta = .29$, $t\ (100) = 2.81$, $p < .01$), design fluency ($\beta = .20$, $t\ (100) = 2.18$ 1, $p < .05$), problem solving ($\beta = -.20$, $t\ (100) = -2.11$, $p < .05$) and deductive reasoning ($\beta = .28$, $t\ (100) = 2.88$, $p < .01$) significantly accounted for variance of performance on the Strange Stories test.

Regression 3: Faux Pas Test

First, a Cook's D analysis was employed in order to determine whether there were any outliers in the data set. Using a Cook's D value of 4/123 (0.0325), five outliers were identified. After removing these five participants from the data set, the regression analysis was re-entered. This model accounted for a significant amount of variance in Faux Pas test scores ($R^2 = .272$, $R^2 change = .130$, $F\ (13,104) = 2.98$, $p < .01$, see Table 3.7). Only problem solving ($\beta = .29$, $t\ (104) = 3.04$ 1, $p < .01$) significantly accounted for variance of performance on the Faux Pas test. Gender also continued to account for a significant amount of variance ($\beta = .37$, $t\ (104) = 4.19$, $p < .01$) in the overall model. An independent-samples t-test revealed that females performed significantly better on the FP test than males ($p < .01$).

Discussion

First, the lack of correlations among the three ToM tests suggest that although all three of the tests used in this study are designed to measure ToM (Baron-Cohen et al., 2001; Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997; Gottlieb, 2005; Gregory et al., 2002; Happé, 1994; Happé et al., 1998; Happé, Winner, & Brownell, 1998; Jolliffe & Baron-Cohen, 1999; Kaland et al., 2002; Maylor, Moulson, Muncer, & Taylor, 2002; Stone, Baron-Cohen, & Knight, 1998; Sullivan, & Ruffman, 2004), they may be each tapping into very different domains. It is not rare for ToM tests to be aggregated into a composite score (Salztman et al, 2000; Fahie & Symons, 2003; Yirmiya et al., 1998). These results, however, suggest that this practice may not be the best manner in which to analyze one's data.

Quite unexpectedly, cognitive flexibility had an inverse relationship with RMET performance. Thus, poorer performance on cognitive flexibility and problem solving was associated with better performance on ToM. The cognitive flexibility variable was the scaled score from condition 4 of the Trail Making Test. This test required a participant to switch between connecting numbers and letters in numerical and alphabetical order in a timed task. The problem solving task required a participant to sort sets of cards into different categories using different sorting rules (Delis et al., 2001). The RMET requires a participant to study the expressions of actors' eyes and determine which emotion they are conveying from four possible choices (Baron-Cohen et. al, 2001).

The RMET has been conceptualized as a ToM task due to the concept that emotion recognition is the foundation of ToM abilities (Baron-Cohen et. al, 2001). The results found in this study suggest that EF domains do not drive emotion recognition tasks, as the inverse relationship simply does not make logical sense. Furthermore, previous research (Ahmed et al., 2007) suggests that the RMET, Strange Stories test, and Faux Pas test measure different domains of ToM since they do not correlate together. Perhaps the aspect of ToM measured in the RMET is so different from the areas of ToM measured by the Strange Stories and Faux Pas tests that it does not include a strong EF mechanism. It should be noted that the Strange Stories and Faux

Pas tests have a strong verbal component, which is unlike the RMET (Baron-Cohen et. al, 2001; Gregory et al., 2002; Happé, 1994; Stone et al., 1998). Furthermore, the fact that WTAR-predicted FSIQ still accounted for significant variance in the RMET further supports the idea that the RMET may not include a strong EF component.

Three domains of EF accounted for a significant and unique amount of variance in the Strange Stories test in a positive direction. They were: verbal fluency, design fluency, and deductive reasoning. The Strange Stories test uses a series of vignettes in which participants have to identify the intentions of the stories' characters (Happé, 1994). Verbal and design fluency require a person to quickly form unique designs and words (Delis et. al, 2001). The results from this study suggest that one needs this ability to quickly comprehend the differing scenarios presented in the Strange Stories test. In terms of real-life behavior, this may suggest that one needs to be able to apply the basic principles of social interactions and other people's intentions into any social situation. Thus, a person does not memorize one type of social interaction, but is able to generalize it to a variety of unique situations, thus utilizing ToM and EF skills. Deductive reasoning relies on the ability to solve a puzzle from clues (Delis et. al, 2001). Since the Strange Stories test requires a person to figure out the intentions of the characters (Happé, 1994), one has to deduce why a character behaved the way he or she did. Thus, these results suggest that for adequate ToM skills, one also has to be able to understand why a person behaves or will behave in a certain situation through understanding and comprehending available clues. For example, a person can use tone of voice to convey different messages (e.g., sarcasm). By using tone of voice as a clue, one is able to understand the intentions and thoughts of the other person. An unexpected inverse relationship occurred with problem solving, which suggests that problem solving skills are unnecessary for one to be able to take the perspective of another person.

In the Faux Pas test, problem-solving was the only EF domain to significantly account for variance in performance on this test of ToM. The problem-solving variable came from the D-KEFS Sorting Test confirmed correct sorts, in which participants have to sort a sets of cards in multiple ways (Delis et. al, 2001). The Faux Pas test requires a participant to simultaneously understand the beliefs of two characters through a series of vignettes (Gregory et al., 2002; Stone et al., 1998). The results from this study suggest that one needs good problem-solving skills in order to understand faux pas, which is the most complex form of ToM (Brüne & Brüne-Cohrs, 2005). Surprisingly, gender was found to continue to account for significant variance in the overall model of Faux Pas test performance.

Limitations to this study include the homogenous sample used and the fact that it was a non-clinical sample. In future studies, it will be important to determine whether these relationships are maintained in a clinical population. Nevertheless, this study aimed to explore the EF-ToM relationship using the D-KEFs and the three ToM tests. This resulted in using a very comprehensive EF battery (Delis et. al, 2001) and three tests that measured different levels of ToM (Baron-Cohen et. al, 2001; Gregory et al., 2002; Happé, 1994; Stone, Baron-Cohen, & Knight, 1998). Furthermore, the fact that a normal population was used is also a strength of this study, as this population had fully developed EF and ToM abilities (Anderson, Levin, & Jacobs, 2002; Brüne & Brüne-Cohrs, 2005). This allowed for a clearer assessment of the EF-ToM relationship. Thus, the results of this study supported an EF-ToM relationship. Furthermore, it supported previous research that suggested that the RMET, Strange Stories test, and Faux Pas test measured different domains (Ahmed et al., 2007), as different EF patterns were found for each test and a lack of correlations were once again found among the RMET, Strange Stories, and Faux Pas tests.

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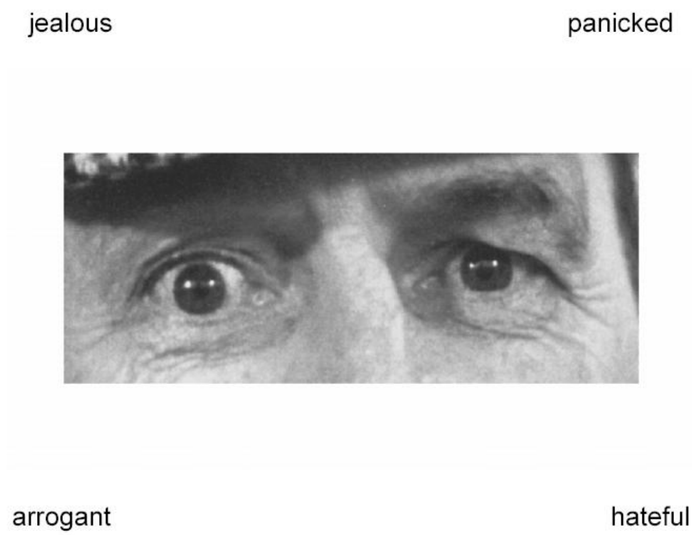

Figure 3.1.

Practice item from RMET (Test used with permission from the developers and the Autism Research Centre)

Jill wanted to buy a kitten, so she went to see Mrs. Smith, who had lots of kittens she didn't want. Now Mrs. Smith loved the kittens, and she wouldn't do anything to harm them, though she couldn't keep them all herself. When Jill visited she wasn't sure she wanted one of Mrs. Smith's kittens, since they were all male and she wanted a female. But Mrs. Smith said, "If no one buys the kittens I'll just have to drown them!"

Question: "Why did Mrs. Smith say that?"

Figure 3.2.

Item from the Strange Stories test (Test used with permission from the developer: Dr. Happé)

"Jill had just moved into a new apartment. Jill went shopping and bought some new curtains for her bedroom. When she had finished decorating the apartment, her best friend, Lisa, came over. Jill gave her a tour of the apartment and asked, 'How do you like my bedroom?' 'Those curtains are horrible,' Lisa said. 'I hope you're going to get some new ones!' (Stone et al., 1998).

Figure 3.3.

Item from the Faux Pas Test (Test used with permission from the developers and the Autism Research Centre)

Table 3.1.

Demographics

	Frequency	Percent	Mean	Standard Deviation
Age			19.04	1.30
Gender				
Male	53	42.7		
Female	70	56.5		
Ethnicity				
White/ Non Hispanic	96	78.0		
African American/Black	6	4.9		
Hispanic/Latino	5	4.1		
Asian/Pacific Islander	14	11.4		
Other	2	1.6		
Family Income				
below $10,000	1	.8		
$10,001-$30,000	7	5.7		
$30,001-$60,000	23	18.7		
$60,001-$90,000	37	30.1		
$90,001 and above	55	44.7		
Geographical Region Raised				
South	106	86.2		
North Central	1	.8		
West	3	2.4		
Northeast	6	4.9		
Other	6	4.9		
WTAR-Predicted FSIQ			108.91	6.90

Table 3.2.

Descriptive Statistics of D-KEFS and ToM Variables

	Minimum	Maximum	Mean	Standard Deviation
D-KEFS: Cognitive Flexibility	4	14	10.78	1.87
D-KEFS: Verbal Fluency	5	19	12.19	3.48
D-KEFS: Design Fluency	4	19	11.98	3.05
D-KEFS: Inhibition	6	19	11.51	2.25
D-KEFS: Problem Solving	1	15	9.13	2.62
D-KEFS: Categorical Processing	5	15	11.54	2.34
D-KEFS: Deductive Reasoning	6	16	11.71	2.11
D-KEFS: Spatial Planning	4	17	11.17	2.18
D-KEFS: Verbal Abstraction	5	100	87.49	28.63
RMET	8	34	27.28	3.75
Strange Stories Test	22	32	27.41	2.23
Faux Pas Test	76	121	112.94	8.58

N = 123
D-KEFS scores based on *M* = 10, *SD* = 3
D-KEFS verbal abstraction based on percent correct
ToM scores based on total correct (RMET: 36 possible points; Strange Stories: 32 possible points; Faux Pas : 121 possible points)

Table 3.3.

Spearman's Rho Correlations for ToM Tests

	RMET	Strange Stories Test	Faux Pas Test
RMET	1.000	0.138	0.130
Strange Stories Test		1.000	0.111
Faux Pas Test			1.000

N = 123
All *p's* < .05

Table 3.4.

Correlation Matrix of D-KEFS and ToM Variables

	CF	VF	DF	I	PS	CP	DR	SP	VA	RMET	Strange Stories	Faux Pas
CF	1.000	.258**	.266**	.278**	.279**	.069	.147	.090	.054	*.031*	*-.012*	*.071*
VF		1.000	.292**	.443**	.217*	.180*	.286**	.025	.111	*.227**	*.218**	*.217**
DF			1.000	.262**	.103	.118	.148	.036	-.020	*.238***	*.191**	*.096*
I				1.000	.264**	.018	.278**	.036	.164	*.218**	*-.002*	*.060*
PS					1.000	.186*	.227*	.074	.206*	*-.087*	*-.049*	*.215**
CP						1.000	.037	.063	.096	*.058*	*.005*	*.188**
DR							1.000	.130	.166	*.210**	*.179**	*.145*
SP								1.000	-.043	*-.031*	*.179**	*.037*
VA									1.000	*.120*	*.079*	*.127*
RMET										*1.000*	*.138*	*.130*
Strange Stories											*1.000*	*.111*
Faux Pas												*1.000*

N = 123
D-KEFS Variables: CF = cognitive flexibility, VF = verbal fluency, DF = design fluency, I = inhibition, PS = problem solving, CP = categorical processing, DR = deductive reasoning, SP = spatial planning, VA = verbal abstraction
Italicized = Spearman's rank-order Correlations, Non-italicized = Pearson's correlations
* $p < .05$, ** $p < .01$

Table 3.5.

Multiple regression analysis for prediction of RMET by D-KEFS tests (all variables entered)

Model 1: R= .45; R^2= .21 *Adj.* R^2= .18 *Std. Err. of Est.*= 2.87 F (4,110) = 7.17, p < .01

Model 2: R= .58; R^2= .34 *Adj.* R^2= .25 R^2 *change* = .13 *Std. Err. of Est.*= 2.73 F (13,101) = 4.00, p < .01

	Variable	Beta	*t*	Significance of *t*	Zero-order correlation	Partial Correlation	Semi-Partial Correlation
Model 2	Age	.078	.518	p > .05	-.174	.052	.042
	Gender	.131	1.511	p > .05	.097	.149	.122
	Years Education	-.174	-1.244	p > .05	-.125	-.123	-.101
	WTAR-predicted FSIQ	.360	3.809	p < .01	.394	.354	.308
	Cognitive Flexibility	-.247	-2.591	p < .05	-.070	-.250	-.209
	Verbal Fluency	.142	1.434	p > .05	.301	.141	.116
	Design Fluency	.082	.923	p > .05	.197	.091	.075
	Inhibition	.167	1.604	p > .05	.282	.158	.130
	Problem Solving	-.175	-1.910	p > .05	-.077	-.187	-.154
	Categorical Processing	.007	.085	p > .05	.098	.008	.007
	Deductive Reasoning	.132	1.465	p > .05	.234	.144	.118
	Spatial Planning	-.060	-.715	p > .05	-.073	-.071	-.058
	Verbal Abstraction	.045	.516	p > .05	.096	.051	.042

N = 115
Dependent variable: RMET total raw score

Table 3.6.

Multiple regression analysis for prediction of Strange Stories Test by D-KEFS tests (all variables entered)

Model 1: *R*= .16; R^2= .03 *Adj.* R^2= -.01 *Std. Err. of Est.*=1.99 *F* (4,109) = .724, *p* > .05

Model 2: *R*= .53; R^2= .28 *Adj.* R^2= .18 R^2 *change* = .25 *Std. Err. of Est.*= 1.79 *F* (13,100) = 2.96, *p* < .01

	Variable	Beta	*t*	Significance of *t*	Zero-order correlation	Partial Correlation	Semi-Partial Correlation
Model 2	Age	.027	.191	*p* > .05	-.137	.019	.016
	Gender	-.036	-.395	*p* > .05	.012	-.039	-.034
	Years Education	-.162	-1.198	*p* > .05	-.106	-.119	-.102
	WTAR-predicted FSIQ	-.060	-.588	*p* > .05	.073	-.059	-.050
	Cognitive Flexibility	-.075	-.761	*p* > .05	-.017	-.076	-.065
	Verbal Fluency	.292	2.807	*p* < .01	.287	.270	.239
	Design Fluency	.201	2.182	*p* < .05	.261	.213	.185
	Inhibition	-.052	-.499	*p* > .05	.083	-.050	-.042
	Problem Solving	-.202	-2.116	*p* < .05	-.086	-.207	-.180
	Categorical Processing	-.041	-.449	*p* > .05	.018	-.045	-.038
	Deductive Reasoning	.277	2.880	*p* < .01	.323	.277	.245
	Spatial Planning	.168	1.895	*p* > .05	.169	.186	.161
	Verbal Abstraction	.023	.260	*p* > .05	.051	.026	.022

N = 114

Dependent variable: Strange Stories Test total raw score

Table 3.7.

Multiple regression analysis for prediction of Faux Pas Test by D-KEFS tests (all variables entered)

Model 1: R= .38; R^2= .14 *Adj.* R^2= .11 *Std. Err. of Est.*= 5.69 F (4,113) = 4.67, $p < .01$

Model 2: R= .52; R^2= .27 *Adj.* R^2= .18 R^2 *change* = .13 *Std. Err. of Est.*= 5.47 F (13,104) = 2.98, $p < .01$

	Variable	Beta	t	Significance of t	Zero-order correlation	Partial Correlation	Semi-Partial Correlation
Model 2	Age	-.148	-1.135	$p > .05$	-.093	-.111	-.095
	Gender	.375	4.190	$p < .01$	.336	.380	.351
	Years Education	.150	1.207	$p > .05$	.032	.118	.101
	WTAR-predicted FSIQ	.048	.491	$p > .05$	.095	.048	.041
	Cognitive Flexibility	-.129	-1.351	$p > .05$	.002	-.131	-.113
	Verbal Fluency	.158	1.572	$p > .05$	.212	.152	.132
	Design Fluency	.011	.118	$p > .05$	.064	.012	.010
	Inhibition	-.057	-.560	$p > .05$	.049	-.055	-.047
	Problem Solving	.288	3.043	$p < .01$	.234	.286	.255
	Categorical Processing	.077	.858	$p > .05$	.144	.084	.072
	Deductive Reasoning	.041	.438	$p > .05$	.136	.043	.037
	Spatial Planning	.088	.998	$p > .05$	.078	.097	.083

N = 118
Dependent variable: Faux Pas Test total raw score

CHAPTER 5

DISCUSSION

This thesis examined the relationship between EF and ToM. Before the main regression analyses were conducted, it was important to determine whether the three ToM tests could be aggregated into a single composite score, as is common in the literature (Salztman et al, 2000; Fahie & Symons, 2003; Yirmiya et al., 1998). It was found that none of the three ToM tests were significantly correlated with each other. This may suggest that although all three of the tests used in this study are designed to measure ToM (Baron-Cohen et al., 2001; Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997; Gottlieb, 2005; Gregory et al., 2002; Happé, 1994; Happé et al., 1998; Happé, Winner, & Brownell, 1998; Jolliffe & Baron-Cohen, 1999; Kaland et al., 2002; Maylor, Moulson, Muncer, & Taylor, 2002; Stone, Baron-Cohen, & Knight, 1998; Sullivan, & Ruffman, 2004), they may be each tapping into very different domains. In fact, there may be differing cognitive processes associated with these different possible domains. Therefore, the practice of combining various ToM tests into aggregate scores may not be the best manner in which to analyze one's data (Salztman et al, 2000; Fahie & Symons, 2003; Yirmiya et al., 1998), and previous data from the pilot study supported this concept as well (Ahmed, Miller, & Abner, 2007). The findings suggest that it is always important to examine concordance when using multiple ToM measures.

The lack of correlations among the ToM tests also indicate that in a normal population, these tests simply do not hold together. Therefore, future directions of this study should investigate whether this finding still holds in a clinical sample, which are the populations ToM tests have predominantly been used for (Baron-Cohen et al., 2001; Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997; Baron-Cohen, Leslie, & Frith, 1985; Gottlieb, 2005; Gregory et al., 2002; Happé, 1994; Happé et al., 1998; Happé, Winner, & Brownell, 1998; Jolliffe & Baron-Cohen, 1999; Kaland et al., 2002; Maylor, Moulson, Muncer, & Taylor, 2002; Stone, Baron-Cohen, & Knight, 1998; Sullivan, & Ruffman, 2004).

Given these implications (i.e., there may be differing cognitive processes that are associated with the apparent different domains of ToM measured by the three ToM tests), three separate multiple regression analyses were conducted with each ToM test as a dependent variable. Specifically, this study explored whether there were differing EF mechanisms associated with each of the three ToM measures, and the relationship between EF and ToM was supported.

Quite unexpectedly, cognitive flexibility had an inverse relationship with RMET performance. Thus, poorer performance on cognitive flexibility and problem solving was associated with better performance on ToM. The cognitive flexibility variable was the scaled score from condition 4 of the Trail Making Test. This test required a participant to switch between connecting numbers and letters in numerical and alphabetical order in a timed task (Delis et al., 2001). The RMET requires a participant to study the expressions of actors' eyes and determine which emotion they are conveying from four possible choices (Baron-Cohen et. al, 2001).

The RMET has been conceptualized as a ToM task due to the concept that emotion recognition is the foundation of ToM abilities (Baron-Cohen et. al, 2001). The results found in this study suggest that EF domains do not drive emotion recognition tasks, as the inverse relationship simply does not make logical sense. Furthermore, previous research (Ahmed et al.,

2007) suggests that the RMET, Strange Stories test, and Faux Pas test measure different domains of ToM since they do not correlate together. Perhaps the aspect of ToM measured in the RMET is so different from the areas of ToM measured by the Strange Stories and Faux Pas tests that it does not include a strong EF mechanism. It should be noted that the Strange Stories and Faux Pas tests have a strong verbal component, which is unlike the RMET (Baron-Cohen et. al, 2001; Gregory et al., 2002; Happé, 1994; Stone et al., 1998). Furthermore, the fact that WTAR-predicted FSIQ still accounted for significant variance in the RMET further supports the idea that the RMET may not include a strong EF component.

Three domains of EF accounted for a significant and unique amount of variance in the Strange Stories test in a positive direction. They were: verbal fluency, design fluency, and deductive reasoning. The Strange Stories test uses a series of vignettes in which participants have to identify the intentions of the stories' characters (Happé, 1994). Verbal and design fluency require a person to quickly form unique designs and words (Delis et. al, 2001). The results from this study suggest that one needs this ability to quickly comprehend the differing scenarios presented in the Strange Stories test. In terms of real-life behavior, this may suggest that one needs to be able to apply the basic principles of social interactions and other people's intentions into any social situation. Thus, a person does not memorize one type of social interaction, but is able to generalize it to a variety of unique situations, thus utilizing ToM and EF skills. Deductive reasoning relies on the ability to solve a puzzle from clues (Delis et. al, 2001). Since the Strange Stories test requires a person to figure out the intentions of the characters (Happé, 1994), one has to deduce why a character behaved the way he or she did. Thus, these results suggest that for adequate ToM skills, one also has to be able to understand why a person behaves or will behave in a certain situation through understanding and comprehending available clues. For example, a person can use tone of voice to convey different messages (e.g., sarcasm). By using tone of voice as a clue, one is able to understand the intentions and thoughts of the other person. An unexpected inverse relationship occurred with problem solving, which suggests that problem solving skills are unnecessary for one to be able to take the perspective of another person.

In the Faux Pas test, problem-solving was the only EF domain to significantly account for variance in performance on this test of ToM. The problem-solving variable came fro the D-KEFS Sorting Test confirmed correct sorts, in which participants have to sort a sets of cards in multiple ways (Delis et. al, 2001). The Faux Pas test requires a participant to simultaneously understand the beliefs of two characters through a series of vignettes (Gregory et al., 2002; Stone et al., 1998). The results from this study suggest that one needs good problem-solving skills in order to understand faux pas, which is the most complex form of ToM (Brüne & Brüne-Cohrs, 2005). Surprisingly, gender was found to continue to account for significant variance in the overall model of Faux Pas test performance.

Limitations to this study include the homogenous sample used and the fact that it was a non-clinical sample. In future studies, it will be important to determine whether these relationships are maintained in a clinical population. Nevertheless, this study aimed to explore the EF-ToM relationship using the D-KEFs and the three ToM tests. This resulted in using a very comprehensive EF battery (Delis et. al, 2001) and three tests that measured different levels of ToM (Baron-Cohen et. al, 2001; Gregory et al., 2002; Happé, 1994; Stone, Baron-Cohen, & Knight, 1998). Furthermore, the fact that a normal population was used is also a strength of this study, as this population had fully developed EF and ToM abilities (Anderson, Levin, & Jacobs, 2002; Brüne & Brüne-Cohrs, 2005). This allowed for a clearer assessment of the EF-ToM relationship. Thus, the results of this study supported an EF-ToM relationship. Furthermore, it supported previous research that suggested that the RMET, Strange Stories test, and Faux Pas test measured different domains, as different EF patterns were found for each test.

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