Executive function predicts theory of mind but not social verbal communication in school-aged children with autism spectrum disorder

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Abstract

Background: The association between Executive Function (EF) and Theory of Mind (ToM) in Autism spectrum disorder (ASD) has been mainly investigated using false belief tasks, whilst less is known about the EF effect on other ToM facets. Furthermore, the role EF plays in social communication in ASD is mainly assessed using parent-report EF ratings rather than direct assessment.

Aims: The aim of this study was to shed more light on the effect of performance-based EF measures on ToM and social communication in middle childhood in ASD relative to neurotypical controls.

Methods and Procedures: Cross-sectional data were collected from 64 matched, school-aged children with and without ASD (8-12 years old), tested on measures of EF (*inhibition*, *working memory*, *cognitive flexibility*), ToM mental state/emotion recognition and social verbal communication.

Outcomes and Results: Significant group differences were observed only in selective EF skills (*inhibition* & *cognitive flexibility*) and social verbal communication. EF working memory contributed to the explained variance of ToM but not social verbal communication in middle childhood.

Conclusions and Implications: These findings suggest that EF and ToM are still associated in middle childhood and EF may be a crucial predictor of ToM across childhood in ASD. Implications are discussed regarding the social-cognitive impairment relationship in ASD.

What this paper adds?

The association between EF and ToM in middle childhood in ASD has been mainly investigated using false belief tasks, whilst less is known about the EF effect on other ToM facets such as mental state/emotion recognition. We found that strong correlations between EF and ToM mental state/emotion recognition are still significant in middle childhood (8-12 years) (over and above age and IQ), which highlights the importance of following the developmental pathway of the interrelation between EF and various ToM facets beyond the preschool period in ASD as well. Such information may help identify the contribution of long-term EF effects on the functional outcomes of children with ASD, and have important theoretical implications for current conceptualisations of the development of both domains. The significant EF-ToM relation in middle childhood suggests that both abilities are

possibly linked across development and these data could provide a solid ground for future longitudinal studies aiming to identify the underlying mechanisms linking EF and ToM in ASD.

1. Introduction

Autism spectrum disorder (ASD) is a multifaceted neurodevelopmental disorder defined by impaired verbal and nonverbal communication, social interactions, and repetitive/restricted behaviours and interests (Diagnostic and Statistical Manual of Mental Disorder— DSM-5, American Psychiatric Association, 2013). Several ASD samples have also been reported to experience deficits in multiple neuropsychological functions, such as Executive Function (EF) and Theory of Mind (ToM) (Losh et al., 2012; Robinson et al., 2009). ToM is multifaceted and refers to the ability to infer beliefs, intents, desires and emotions (Korkmaz, 2011), in order to explain or predict behaviour (Wimmer & Perner, 1983). EF refers to a set of future-oriented and goal-directed cognitive skills that are crucial for problem solving and social behaviour (Anderson, 1998). Several studies have reported strong associations and that the emergence of ToM is dependent on EF (Best, Miller, & Jones, 2009; Carlson, Moses, & Claxton, 2004; Devine & Hughes, 2014; Hughes & Ensor, 2007). As children continue to develop both EF and ToM during middle childhood and adolescence (Davidson et al., 2006; Devine & Hughes, 2013; Huizinga et al., 2006), there is a vast body of research indicating that ToM abilities remain associated with EF during middle childhood in typical development (Bock, Gallaway, & Hund, 2015; Im-Bolter, Agostino, & Owens-Jaffray, 2016; Lagattuta et al., 2014).

Within the autism spectrum, growing evidence of significant EF deficits across development in aspects such as cognitive flexibility (the ability to switch between thinking about two different concepts; Hill, 2004; Verté et al., 2005), working memory (the ability to store and manipulate information; Alloway et al., 2009; Geurts et al., 2004), inhibition (the ability to inhibit irrelevant information; Christ et al., 2007; Happé et al., 2006) and planning (constant monitoring and (re)-evaluation of sequential actions in order to achieve a goal; Kimhi et al., 2014; Verté et al., 2005) have been reported in middle childhood and adolescence. Thus one of the competing theories trying to explain the ASD symptomatology, namely the Executive Dysfunction theory, has suggested that disruptions in EF may likely contribute to impairments in ToM and broader social cognition for children with ASD (see for a review, Hill, 2004; Russell, 1997). Theoretically, ToM and EF could be associated only in early childhood when both abilities emerge (Moses, 2001). Evidence of EF-ToM associations

later in development though, for example middle childhood (e.g. Austin, Groppe, & Elsner, 2014; Bock et al., 2015; Im-Bolter et al., 2016), suggests that both abilities may be linked across the lifespan as they share overlapping tasks demands and cognitive competencies (Bock et al., 2015). However, less is known about the association between EF and ToM in ASD. Examining such relations in ASD could provide a better understanding of the nature of these links.

While executive dysfunction is widely studied in ASD (e.g. Demetriou et al., 2017), research examining the association between EF and ASD behavioural symptoms (i.e. social communication difficulties and repetitive/restricted behaviours) is limited (Leung et al., 2016). Some findings suggest that EF disruptions may associate with repetitive/restrictive behaviours (e.g., D'Cruz et al., 2013; Miller, Ragozzino, Cook, Sweeney, & Mosconi, 2015; Mosconi et al., 2009; Reed et al., 2013; Yerys et al., 2009), whereas social communication deficits are most commonly associated with social cognition aspects in ASD (e.g. Ames & White, 2011; Lerner, Hutchins, & Prelock, 2011; Nagar Shimoni, Weizman, Yoran, & Raviv, 2012). Taking this evidence together, it seems that the role EF plays in social communication in ASD is not fully understood yet. The present study focused on determining whether these abilities are associated in middle childhood in ASD.

1.1. EF and ToM in ASD

Research has indicated that impairments in EF and ToM are associated within ASD (e.g. Demetriou et al., 2017). Regarding the preschool period, evidence from Pellicano's cross sectional (2007) and longitudinal (2010) studies has shown that EF skills (i.e. planning, cognitive flexibility, and inhibition) of young children with ASD (4-7 years) were significantly correlated with and contributed to the development of ToM, even after partialling out the effects of chronological age, verbal, and non-verbal ability. More recently, Kimhi et al. (2014) found that ToM and two EF aspects (cognitive flexibility and planning) were significantly associated in young children (5 years) with ASD. These findings indicate that, similar to typical development, there is a strong association between EF and the ToM acquisition/ expression in young children with ASD.

Converging evidence from the investigation of the EF-ToM relationship beyond the preschool period in ASD has shown that ToM performance was significantly correlated with EF aspects (e.g. inhibition, planning, and working memory) in children and adolescents (5-14 years) with ASD (Joseph & Tager-Flusberg, 2004). A subsequent longitudinal study of the same authors (Tager-Flusberg &

Joseph, 2005) revealed that EF was still associated to ToM after one year in children and adolescents with ASD (5-14 years). Both these studies however did not use a control group (of typical development) and thus clear conclusions about whether children's performance was consistent with their age or ability could not be drawn. Finally, Ozonoff et al. (1991) also reported significant correlations between selective EF aspects (planning, cognitive flexibility, and working memory) and ToM abilities in children and young adults (8-20 years) with ASD. It should be noted at this point that the aforementioned studies have addressed mainly false belief (understanding that one's belief/ representation about the world can contrast with reality) tasks to measure ToM. There is only one study (Cantio et al., 2016) to date that examined the ToM and EF relationship in middle childhood (8-12 years) using other than false belief ToM tasks (i.e. Strange Stories and Frith-Happé animations), with results showing significant correlations between EF and these ToM measures tapping mental state explanation. Less is known about the association of EF to emotion recognition abilities that are theoretically considered to be equally fundamental aspects of ToM and empathising in general (Golan et al., 2006). Indeed recent evidence has suggested that ToM should not be considered a single process as it includes two levels: cognitive and affective (Baron-Cohen et al. 2015; Franco et al., 2014; Mazza et al., 2014, 2017; Shamay-Tsoory et al., 2009). Cognitive ToM refers to the ability to understand one's mental states (e.g. what they're thinking), while affective ToM is the ability to infer one's emotions (Franco et al. 2014; Mazza et al. 2014, 2017). ToM tests such as the Reading the Mind in the Eyes (Baron-Cohen et al., 2001), despite tapping both mental state and emotion recognition abilities, are not as widely used in ASD. The latter test, addressed in the present study, requires participants to recognise one's emotional or mental state looking at their eyes. Theoretically, ToM is thought to heavily rely on the direction of the gaze of the observed person (Baron-Cohen et al., 2001), which is a significant cue for social interaction (Emery, 2000). As ToM ability may differ depending on the modality of eyes or body expression (Olderbak et al., 2015; Slaughter & Repacholi, 2003), it is critical for children to be able to make accurate attributions about the thoughts and emotions of others, in order to appropriately interact in social situations (Crick & Dodge, 1994). It would be crucial to shed more light on the extension of the relation between EF and various aspects of ToM such as mental state/emotion recognition to middle childhood, as it may have important theoretical implications for current conceptualisations of the development of both domains. Middle childhood is defined by rapid cognitive and developmental changes and despite the significant

evidence from early childhood, studies in middle childhood could provide a solid ground for future longitudinal research aiming to identify the underlying mechanisms linking EF and ToM.

1.2. Social communication and EF in ASD

Social communication impairments are a core deficit and an early indicator of ASD (Anagnostou et al., 2014; Vicker, 2009). Children and adults with ASD have been found to show difficulties in aspects such as play, eye gaze, reciprocal social interactions, imitation, joint attention and face processing (Dawson et al., 2004; Klin, 2006; Vicker, 2009), while evidence from empirical studies over the last decade has indicated a high variability in the manifestation of these deficits across the lifespan (Bryson et al., 2007; Lord et al., 2006). EF has been considered to play a key role in facilitating children's effective social communication and interactions. EF is specifically thought to support the manipulation of information of another's perspective, in order to guide communicative behaviours (Nilsen & Ferica, 2011). For example, speakers need to hold one's communicative information in working memory or inhibit their personal views, in order to produce effective statements. Cognitive flexibility may also be needed, as communicative partners must process their thoughts flexibly and alter their message depending on their audience (Nilsen, Varghese, Xu, & Fecica, 2015; Wardlow, 2013).

The discussion of the relationship between social communicative impairments and EF in ASD is very limited to date and has yielded mixed results. Recent studies have provided evidence of a significant association between EF and social communication deficits in ASD (e.g. Dichter et al., 2009; Kenworthy et al., 2009; Pugliese et al., 2015) but failure of this relationship to reach statistical significance has also been reported (e.g., Cantio et al., 2016; Jones et al., 2017; Joseph & Tager-Flusberg, 2004; Landa & Goldberg, 2005). Clear conclusions about the role that EF plays in social communication have not been reached yet, mainly due to methodological discrepancies and the little overlap in the EF tests addressed in the aforementioned studies. For example, Kenworthy et al. (2009) and Pugliese et al. (2015) reported significant associations only when parent-report EF ratings (e.g. BRIEF; Gioia, Isquith, Guy, & Kenworthy, 2000) were addressed, while Dichter et al. (2009) addressed only one performance-based EF aspect (i.e. generativity). The present study attempted to further investigate whether the EF-social communication association can be actually generalised to several other, performance-based, EF measures.

Evidence of very low or even non-significant correlations between rating scales and performance-based tasks of EF (e.g. Anderson, Anderson, Northam, Jacobs, & Mikiewicz, 2002; Bodnar, Pralune, Cutting, Denckla, & Mahone, 2007; Mahone et al., 2002) has actually raised questions about the nature of these two seemingly similar measures and appears to indicate that performance-based tests and rating scales may tap different constructs of the multifaceted EF system (McAuley et al., 2010; Toplak et al., 2008). From an operationalisation perspective, performance-based and rating measures of EF differ in the basis of administration and scoring. Performance-based measures are administered in standardised conditions, while presentation is carefully controlled in order for each participant to experience the task the same way. Performance is also assessed not only at the level of accuracy, but also response time or speeding responding under a specific time frame. The rating scales of EF on the other hand capture either the teachers' or parents' reports of the level of competence of examinees in complex, every day, problem-solving situations (Roth et al., 2005). It could be thus assumed that rating scales measure mainly behaviours (i.e. goal pursuit) that are related to the EF processes, rather than the EF processes (i.e. efficiency in cognitive abilities) per se. Imaging evidence finding different neuroanatomical correlates for rating scales and performance-based EF measures (Faridi et al., 2015) has provided further support on the independence of the two types of EF measures. The fact that rating EF scales perhaps measure different cognitive processes of EF relative to neuropsychological tests does not mean that their validity should be questioned. Such findings simply highlight the need to investigate the contribution of both EF types to children's social functioning.

1.3. Current Objectives

The current study mainly focused on the investigation of the association of ToM as well as social verbal communication to EF in middle childhood in ASD. The extension of the EF–ToM relation to middle childhood in ASD has been mainly investigated with false belief tasks and less is known about the EF effect on ToM facets such as mental state/emotion recognition in older children with ASD relative to controls. Research in middle childhood could aid in shedding more light on whether EF-ToM patterns found in early life persist across the course of children's development (McAlister & Peterson, 2013) and is hoped that more theoretical clarity about these interrelated cognitive domains will be provided. Based on previous evidence (Austin et al., 2014; Joseph & Tager-Flusberg, 2004;

Pellicano, 2010), it was hypothesised that EF deficits would relate to ToM mental state/emotion recognition over and above control variables (age and IQ) in ASD and typical development.

Regarding the social verbal communicative impairments, research on their association to EF has yielded mixed results in ASD to date, while the majority of these studies have explored this relation using only parent-report EF measures (Leung et al., 2016; Pugliese et al., 2015) and archival clinical data without control groups (Kenworthy et al., 2009). The association between performance-based EF measures and parent-report EF scales have been reported very low (Anderson et al., 2002; Toplak et al., 2013; Vriezen & Pigott, 2002), while it is presumed that performance-based and parent-report EF measures actually assess different aspects of EF (Eycke & Dewey, 2016; Toplak et al., 2013). Thus the present study attempted to investigate whether performance-based EF measures are also significant predictors of social verbal communication in middle childhood in ASD.

Group differences between control and ASD participants in each EF (*working memory, cognitive flexibility, & inhibition*), ToM, and social verbal communication were examined prior exploring the aforementioned interrelations, in order to corroborate the well-established social and executive dysfunction of ASD in middle childhood as well. The EF aspects of inhibition, working memory and cognitive flexibility were chosen as predictor variables as it is general agreed they are three core EF skills (e.g., Diamond, 2013; Lehto et al., 2003, Miyake et al., 2000). From these core, higher-order EF, other skills such as such as reasoning, problem solving, and planning are built (Collins & Koechlin 2012, Lunt et al. 2012). Also it has been found that several ASD samples present deficits in these cognitive skills (Hill, 2004).

2. Methods

2.1. Participants

Thirty-three children with ASD (22 males) (8 years- 12 years; 11 months) (M=10.34 years, SD=1.29) and 32 control participants (16 males) (8 years; 2 months- 12 years; 10 months) (M=10.00 years, SD=1.35) were recruited. Participants in the ASD group were recruited from parental support groups and autism organisations, while the control participants were identified from the University of Edinburgh's Developmental Lab database and local schools. All participants in the ASD group were previously diagnosed by experienced clinicians, and met the DSM-5 (American Psychiatric

Association, 2013) diagnostic criteria for an ASD. Exclusion criteria included the presence of comorbid conditions (i.e. ADHD, seizures, or colour blindness), a diagnosed psychiatric illness, and Full Scale Intelligence Quotient (FSIQ) below 70 (as determined by the abbreviated version of the Wechsler Intelligence scales (WASI; two subtests: vocabulary and matrix reasoning, Wechsler, 1999)). One case in the ASD group was excluded due to these criteria, resulting in a final ASD group size of 32 children. The clinical diagnoses were also corroborated using the Social Responsiveness Scale (SRS-2; Constantino & Gruber, 2012) to quantify ASD traits. Participants in the control group were included only if they had no diagnosis, and no family history of ASD, or other developmental disorder. Both groups were matched for chronological age ($t (62)$ = -1.05, p = .3). However, the control group's FSIQ (M=114.81, SD= 9.98) was significantly higher relative to the ASD group (M=100.69, SD=12.85) ($t (62)$ = 4.91, $p < .01$). Parents gave informed consent (consistent with the Declaration of Helsinki) before participating in the study in compliance to the University of Edinburgh Psychology Ethics Committee. Table 1 presents participants' characteristics across the two groups.

[Table 1 should be placed here]

2.2. Measures

Delis- Kaplan Sorting Test (D-KEFS; Delis et al., 2001).

Cognitive flexibility was measured by this sorting test that consists of two conditions: Free Sorting and Sort Recognition. In Free Sorting children were presented with six cards mixed of both perceptual patterns and stimulus words. Children had to sort the cards into two groups multiple times using a different sorting criterion each time, in order to achieve as many different sorting combinations as possible (eight target sorts maximum). The participants were to describe the concepts they used to generate each categorisation. In the second condition, Sort Recognition*,* each sort was generated by the researcher while the children were to identify the correct categorisation rule used in each sorting. Successful performance required cognitive flexibility as children needed to switch between thinking about different concepts and was scored in terms of accuracy of the sorting responses and description of the sorting rule. Standardised scores were used.

Delis-Kaplan Word/Colour Interference (D-KEFS; Delis et al., 2001).

In this Stroop-like test assessing children's *inhibition* participants were presented with words of colour names printed in a different-coloured ink and were to name the colour of the ink that the letters were printed and not read the words. Children needed to resolve the interference that arose between the two conflicting tasks in order to select the correct response. Children completed 32 congruent and 32 incongruent trials. Performance was scored based on the numbers of errors made. Standardised scores were used (higher scores indicated better performance).

Working Memory Digit recall and Backwards Digit recall (WMTB-C; Pickering & Gathercole, 2001).

Verbal working memory ability was measured by both Digit and Backwards Digit recall tasks. Children were orally presented with sequences of digits for immediate recall in the exact same order as presented by the examiner (e.g., "Listen carefully and then say the list back to me in the exact same order 12469"). When a child responded correctly to 4 trials within a block, the researcher proceeded to the next block while the sequence length increased progressively. Digits were presented in an even monotone at a rate of 1 per second. In the backwards digit recall task, series of numbers should be repeated in the reverse order. Specifically, children were asked to recall the list starting with the last item heard and end with the first item presented (e.g., '4598' would become '8954'). When a participant responded correctly to 4 trials within a block, the examiner proceeded to the next block while the sequence length increased progressively. Digits were presented in an even monotone at a rate of 1 per second. The composite working memory variable used in the analysis was computed by adding the digit recall and backwards digit recall standardised scores provided.

Reading the Mind in the Eyes (children's version; Baron-Cohen et al., 2001).

This mental state/emotion recognition task is an advanced ToM test assessing children's ability to decode the thoughts and emotions of others from the eyes. It is suggested to have good reliability (Fernández-Abascal, Cabello, Fernández-Berrocal, & Baron-Cohen, 2013; Vellante et al., 2013) and can also be considered an emotion recognition test (Vellante et al., 2013). It consists of photographs of the eye region of 28 faces. The participants were required to make a choice between four words printed at the bottom of the page on which the picture appeared and to choose the one that best describes what the individual in the photograph was thinking or feeling. Successful

performance on all 28 items required children to choose the correct emotion or mental state. If participants said that any term was quite right they were nevertheless asked to choose one of the terms, thus conforming to a forced-choice procedure. One point was given to each correctly reported response.

Children's Communication Checklist (CCC; Bishop, 1998)

This 70-item parent-report questionnaire measures *social verbal communicative skills*. It engages with the assessment of pragmatic abnormalities demonstrated in social verbal communication tapping aspects of verbal fluency, coherence, context, inappropriate initiation, stereotyped conversation, and rapport (subscales). A composite score is derived from the aforementioned scales. It uses a 3-point Likert scale (does not apply, applies somewhat, definitely applies). Interrater reliability for the CCC has been found to be 0.80 overall (range of scales = 0.62 to 0.83; Bishop, 1998).

Social Responsiveness Scale–Second Edition (SRS-2; Constantino & Gruber, 2012)

The SRS-2 is a 65-item questionnaire that measures deficits in social behaviour related to ASD. It uses a 4-point Likert scale (not true, sometimes true, often true, and almost always true). It has shown good test–retest reliability ranging from .88 to .95 and high specificity (92%) (Bruni, 2014). We used SRS to corroborate clinical diagnoses of ASD.

2.3. General Procedure

Children were assessed during one visit (90 minutes), in a quiet room at the University's Developmental lab or at their school. Two female experimenters assessed the children. The WASI subtests were always used first, whereas the order of the other tests was randomised across the participants. Children's responses were scored at the end of each assessment. Breaks were included when necessary.

2.4. Statistical Analysis

Statistical analyses were performed using SPSS-23®. Variables were checked for normality and homogeneity assumptions of parametric tests and no outliers were found. Multivariate analysis of

covariance (MANCOVA) and follow up analyses of covariance (ANCOVAs) (adjusted for FSIQ) were conducted to perform between-group comparisons for each EF, ToM, and social verbal communication measures. Pearson's correlations were performed to examine the relationships between EF, ToM, and social verbal communication within the two groups separately. Finally the extent to which each one of the individual EF components predicted ToM and social verbal communication (over and above age and FSIQ) in ASD and typical development was investigated by performing linear hierarchical regression analysis. All tests were two-tailed and statistical significance was set at $p < .05$.

3. Results

3.1. Group Differences

The EF performance of ASD and typically developing controls was first compared using MANCOVA (FSIQ as covariate). Results showed that there was a significant group difference in EF performance overall ($\lambda = .83$, $F(3, 58) = 3.86$, $p = .014$, $\eta^2 = .16$). Results of the follow up ANCOVAs demonstrated group differences in children's performance on the interference ($F(1, 62) = 5.58$, $p = .02$, $\eta^2 = .09$) and sorting tasks ($F(1, 63) = 7.47$, $p = .008$, $\eta^2 = .11$). The ASD group performed significantly worse in the sorting and interference tasks relative to controls. No significant group differences were found in the digit span task ($F(1, 63) = .17$, $p = .68$, $\eta^2 = .003$) (see table 2 for means and standard deviations).

ANCOVAs (adjusted for FSIQ) were performed to examine group differences in ToM and social verbal communication. A significant group difference emerged only in CCC ($F(1, 63) = 124.72$, $p < .01$, $\eta^2 = .67$) while for the Eyes Test analysis did not reveal a significant group effect, $F(1, 63) = .49$, $p = .49$, $\eta^2 = .008$. The social verbal communicative skills of children with ASD were significantly lower than their typically developing peers (see Table 2 for means and standard deviations)

[Table 2 should be placed here]

3.2. Associations between EF, ToM, and social verbal communication

Correlational analyses indicated that EF and ToM were significantly but selectively correlated in both groups. Table 3a indicates that in controls, the Eyes Test was significantly correlated only with

the digit span and interference task. No significant correlations were found between CCC and any of the EF measures. In terms of the ASD group, the Eyes Test was positively correlated with all EF tasks, while CCC was significantly correlated only with digit span and sorting task. [Table 3a&b should be placed here]

Table 3a shows that individual differences in ToM, social verbal communication, and EF variables were significantly related to control variables (FSIQ and age). Thus, supplementary correlational analysis examining the relation among these variables was conducted again, partialling out the effects of age and FSIQ. When FSIQ and age were partialled out, all correlations dropped to non-significance in the control group. In the ASD group, the Eyes Test remained significantly correlated only with the interference task along with the digit span. CCC did not remain significantly related to any EF measure (see table 3b).

Regarding the investigation of which EF aspect is a significant predictor of ToM and social verbal communication, a hierarchical multiple regression was run including the Eyes Test as the dependent variable. CCC was not included in this analysis, as partial correlations revealed no significant associations to EF aspects over and above control variables. Predictors were entered as follows: a) the first step introduced the ASD diagnosis (ASD/typical), b) the second step included FSIQ and age, and finally c) the third step introduced the EF aspects (digit span scores, interference, and sorting task scores). [Table 4 should be placed here]

Table 4 shows that the ASD diagnosis entered in the first step significantly explained 6.4% of the variance in Eyes Test scores, $F (1, 61) = 4.19$, $p= .04$. For FSIQ and age entered next, the total variance explained rose to 19.2%, representing a significant increase of 12.8%, $F (2, 59) = 4.68$, $p = .013$, of additional variance explained. The EF aspects included at the third step rose total variance explained to 38.3% (adding 19.1%), [$F (3, 56) = 5.78$, $p = .002$], over and above the diagnosis and control variables. Digit span scores were predictive of the Eyes Test scores ($p= .026$).

4. Discussion and Implications

The main aim of this study was to examine group differences and the relationship between performance-based EF, ToM, and social verbal communication in middle childhood in ASD relative to typical development. Moderate but significant correlations between EF and ToM (after controlling for age and IQ) were found, while working memory significantly predicted ToM across middle childhood in ASD and typical development. This evidence, in line with a recent similar study in adolescents with ASD (Jones et al., 2017), adds to the existing literature by showing that performance-based EF measures still share a significant relationship with ToM but not with social verbal communication in middle childhood in ASD, in contrast to previous studies that used parent-report EF measures.

4.1. Group differences

Results showed that children with ASD presented specific deficits in EF (i.e. inhibition and cognitive flexibility) and social verbal communicative skills compared to typically developing children of the same age. No significant differences were found in ToM mental state/emotion recognition and verbal working memory abilities between the two groups. The present selective EF deficits in inhibition and cognitive flexibility are consistent with previous studies (Christ, Holt, White, & Green, 2007; Happé, Booth, Charlton, & Hughes, 2006; Hill, 2004; Pellicano, 2007; Yerys et al., 2009) and suggest that EF disruptions are a salient characteristic of several ASD samples across middle childhood. The lack of significant group differences in working memory is in line with previous research suggesting that children with ASD demonstrate intact verbal working memory abilities in school age (Ozonoff & Strayer, 2001; Russell et al., 1996; Williams et al., 2005). As there are however some reports of deficient verbal working memory in ASD (Alloway et al., 2009; Bennetto et al., 1996; Joseph et al., 2005), it has been argued that studies showing intact verbal working memory in ASD perhaps address tasks in which the working memory demand is not sufficiently high (Joseph et al., 2005). That could also be the case in our study. Generally, there is an ongoing debate about the performance of ASD participants on verbal working memory tasks, which reflects a major point of interest in investigating the set of cognitive strengths and weaknesses in ASD. More research is needed to clarify this issue.

The reported impairments in social verbal communicative skills converge with the social dysfunction theory of the ASD phenotype, clinically defined by social deficits (Holloway et al., 2014). The measure used to assess social verbal communicative deficits here was Bishop's (1998)

Communication Checklist with subscales measuring aspects of speech output, syntax, inappropriate initiation, coherence, stereotyped conversation, fluency, and rapport. The significant communicative deficits found in the present study are in line with prior research indicating that children with ASD present difficulties using language effectively or staying in context on conversations, delivering in-depth monologues or make statements which are socially inappropriate (Landa & Goldberg, 2005). Moreover, an important point of interest in our study was the assessment of ToM mental state/emotion recognition in ASD. The Eyes Test used in the present study assessed children's ability to recognise or infer one's emotional or mental state. Such ability is fundamental to understand and effectively communicate with other people when interacting socially. Results indicated that children with ASD had no significant differences in ToM mental state/emotion recognition relative to the control group. These results are in line with Kimhi et al.'s (2014) study reporting that young children with ASD (3-6 years) performed successfully in tasks requiring children to understand and explain basic emotions such as "happy or sad"(happy/sad) relative to the control group. The present study however, included recognition and attribution of more advanced emotions and mental states such as 'cross' or 'daydreaming' which older children with ASD managed to process successfully. Thus, in contrast to previous research (Golan et al., 2007; Rieffe et al., 2000), these results suggest that older children with ASD may not encounter mentalizing problems even when they process high-order, complex or atypical emotions.

4.2. Associations between EF, ToM, and social verbal communication

In line with our hypotheses, results showed small and selectively moderate correlations between EF and ToM in ASD, independent of age and IQ. This evidence is in line with previous research having indicated that individual differences in EF aspects and ToM in ASD were positively related not only in early childhood (Kimhi et al., 2014; Pellicano et al., 2007) but middle childhood (Cantio et al., 2016; Joseph & Tager-Flusberg, 2004) as well. It is well established that EF and ToM abilities share a similar developmental pathway with both abilities undergoing major development across young childhood (Pellicano, 2010). Our results demonstrated that the association between working memory, inhibition and ToM mental state/emotion recognition remained significant, independent of control variables only in the ASD group. Carlson et al. (2002) argue that inhibition and working memory are strong predictors of the emergence and evolution of ToM in typical development,

especially in early childhood as shown by relevant studies (Carlson, Moses, & Breton, 2002; Carlson & Moses, 2001; Devine, White, Ensor, & Hughes, 2016; Hala, Hug, & Henderson, 2003). Children need to inhibit their personal views when processing one's mental/emotional perspectives, in order for them to consider other people's feelings or thoughts (Birch & Bloom, 2004). Furthermore, working memory may allow for the simultaneous processing in the mind of both one's own and another's perspective. Moses and Carlson (2004, p.135) expanded this theoretical notion by proposing that "effective social cognition is not possible unless one is able to hold in mind relevant perspectives (working memory) and to suppress irrelevant ones (inhibition)". Our results thus highlight the significant role inhibition and working memory abilities play in ToM thinking in ASD as well. ASD participants who performed better in the interference task (inhibition) were more able to suppress their own mental/emotional sates or irrelevant ones when processing other people's perspectives in the Eyes task. The moderate but significant correlations reported between EF and ToM in the present study are of particular importance as they demonstrate that both constructs remain associated in middle childhood only in ASD. This specificity could imply that children with ASD may be in greater need of their EF abilities in order to infer mental states/emotions and widen their social horizons through sophisticated social interactions with peers as they grow old. These findings highlight the importance of implementing more training studies aimed at enhancing inhibitory control and/or working memory within ASD as these could potentially remediate children's ToM abilities. We assumed that the lack of significant associations between EF and ToM in the control group (when control variables were adjusted) could be attributed to the use of a more general intellectual ability (FSIQ) in the present study relative to previous studies (Austin et al., 2014; Carlson et al; 2004) that controlled only for verbal ability. For example, in Hughes's (1998), Charman et al.'s (2001), and Carlson et al.'s (2002) studies, in which general intelligence was controlled (FSIQ) (as in the present study), the correlations between EF and ToM aspects did not remain significant in typical development.

Preliminary correlational analysis suggested that performance-based EF abilities (working memory and cognitive flexibility) were significantly associated to social verbal communicative skills only within ASD. However, contrary to our hypotheses, this emerging association dropped to non-significance when control variables were adjusted for. This finding was unexpected as cognitive flexibility has been found to regulate communication and language development in general within

ASD populations (Landa & Goldberg, 2005). One possible explanation for the lack of a significant EF-social communicative skills association could be either the small sample size, or the inclusion of a parent-report questionnaire to assess social communicative skills. The use of a performance-based communication measure might have revealed significant correlations independent of control variables. However, it could be simply the case of performance-based EF skills not explaining much variance in children's social verbal communication skills relative to parent-report EF measures (Kenworthy et al., 2009; Pugliese et al., 2015). Different results across various studies investigating the EF-social communication association may be potentially influenced by the complexity of the EF construct. As already discussed in Introduction, discrepancies in results may be due to performance-based EF measures tapping different cognitive EF aspects relative to rating scales. Toplak et al. (2013) posit that performance-based EF measures assess the algorithmic level of cognitive analysis, focusing on the efficiency of information processing mechanisms (e.g., working memory). Rating EF scales in contrast probably tap more the competence of examinees in every day, problem-solving situations; in other words behaviours (i.e. goal pursuit) that relate to EF processes rather than the actual processes per se. Considering also the fact that the studies (e.g. Leung et al., 2016; Pugliese et al., 2015) that investigate the EF-social communication relation traditionally use questionnaires to measure both concepts (not only EF) suggests that there may be an artificial increase in the associations as the informants may be the same (even more when some of the questions on both questionnaires may actually overlap). EF is a multifaceted, non-unitary construct encompassing several distinct cognitive processes and behaviours. Future studies with larger group sizes and a multilevel approach of EF assessment (by addressing both parent-report and performance-based) would be more informative than capturing only the variance of one or another type of measure. It should be noted at this point that both cognitive levels of analysis are important for clinical practice; combined together could serve as a valuable source of information by providing a more complete and ecological profile of the cognitive strengths and limitations of children.

4.3. Contributions of EF to ToM variance

Several studies have indicated the predictive relation between EF and ToM both in typical development and ASD in young childhood (Carlson et al., 2004; Hughes & Ensor, 2007; Pellicano, 2010). The regression analysis conducted in the present study indicated that EF working memory

made significant contributions to ToM mental state/emotion recognition variance, over and above the control variables in children with and without ASD in middle childhood as well. Our results are in line with evidence suggesting that working memory is a crucial factor to children's emotion comprehension (Morra et al., 2011). Theoretically, these results support the neo-Piagetian theories (Pascual-Leone & Johnson, 2011), proposing that working memory significantly contributes to children's cognitive development in general. According to these theories, working memory is needed to some extent in order for children to construct novel and complex cognitive structures. Such cognitive structures (i.e. the recognition of more complex mental/emotional states as tapped by most items of the *Reading the Mind in the Eyes* task) are likely to require a heavier load of working memory in middle childhood as children with and without ASD have to maintain and manipulate new, complex information (i.e. other people's emotional or mental states) during their social interactions (Brüne, 2003). More specifically, it could be argued that the recognition and determination of the appropriate emotions for different social contexts may require the active maintenance and manipulation of both one's own perspectives and information regarding external, social or emotional cues. Accordingly, it has been proposed that social interactions could be considered as a dual task (i.e. balancing one's own perspectives with those of the other people interacting with), and as such may require working memory mechanisms (Baddeley et al., 1997). The present evidence of working memory contributing to the explanation of ToM variance not only supports the working memory hypothesis arguing that working memory plays a significant role in children's ToM performance in early childhood (Davis & Pratt, 1995) but also extends this in middle childhood in typical development and ASD as well.

4.4. Limitations and Future Directions

The present study corroborated and extended findings from previous studies addressing the relationship of EF, ToM, and social verbal communicative skills in middle childhood in ASD. Although it was found that EF remained significantly associated to ToM mental state/emotion recognition in middle childhood, this study had several limitations. Firstly, the group of ASD participants included only high cognitively able students that could possibly limit the generalisation of the results to the broader spectrum of children with ASD. In addition, due to methodological restrictions, the ASD group was only age and not IQ matched to controls. Secondly, the sample sizes were relatively small and low statistical power could have been a limitation in identifying further associations or significant predictors in our analyses. Furthermore, the use of a single test used to assess ToM and social verbal

communication respectively resulted in the examination of a limited number of potential associations with EF. The inclusion of more than one task for each domain in future studies could yield more conclusive results. Finally, as the ToM task we addressed in the present study has been recently criticised for indexing mainly emotion recognition rather than ToM (e.g. Oakley, Brewer, Bird, & Catmur, 2016), future studies in middle childhood should consider investigating the EF-ToM relation by addressing other various ToM tasks such as the Faux Pas Test (Baron-Cohen, O'Riordan, Jones, Stone, & Plaisted, 1999) , the Strange stories (Happé, 1994) or the Comic Strip Task (Cornish et al., 2010; Sivaratnam et al., 2012). Especially in terms of EF, future studies should investigate whether these results generalise across several other performance-based EF components such as planning or reasoning. Thus, caution should be taken when interpreting the present results and future longitudinal studies should be crucial in establishing links among these abilities.

5. Conclusion

The present study suggests an interrelation between ToM and EF in ASD in middle childhood. Thus, more attention should be given regarding the design of interventions for school-aged children with ASD. Intervention projects targeting the boosting of EF aspects that facilitate ToM mental state/emotion recognition of children with ASD in middle childhood could yield significant results in terms of academic achievement and socialisation. To conclude, the relation between EF and social development especially in ASD is complex and multifactorial. Future studies, especially longitudinal ones will be crucial in order to further identify the developmental trajectories of EF of children with ASD and precisely define whether EF is crucial for social outcomes in ASD.

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Table 1. Participants' characteristics

| | Group | | |
| | ASD | Control | Group Differences |
Variable	(*n*=32)	(*n*=32)	*t-test*
Age (in years)			
M (SD)	10.34 (1.29)	10.00 (1.35)	-1.05
Range	8-12	8-12	
FSIQ total score			
M (SD)	100.69 (12.85)	114.81 (9.98)	4.91**
Range	76-136	87-136	
SRS scores			
M (SD)	167.69 (19.96)	116.31 (5.78)	-13.98***
Range	111-203	106-129	

Note. *p <. 05, **p < .01, ***p < .001

Table 2. Group (ASD/Control) Means for EF, ToM, and social verbal communication

	Group				
	ASD (*n* = 32)		Control (*n* = 32)		Group Differences
Domain and Measure	*M*	*SD*	*M*	*SD*	*F*
EF					
Digit Span	193.67	43.27	221	37.28	.17
Interference Task	9.48	3.05	12.22	1.41	5.58*
Sorting Task	8.94	2.64	12.25	2.71	7.47**
Outcomes					
EyesTest	18.34	4.05	20.16	2.88	.49
CCC	70.06	17.89	123.09	11.37	124.72**

Note. *p <. 05, **p < .01, ***p < .001

Table 3a. Pearson's Correlation Coefficients between ToM, social verbal communication, and EF variables in both groups.

ASD (n=32)	FSIQ	Age	Digit Span	Sorting Task	Interference Task	EyesTest	CCC
FSIQ		.25	.47**	.49**	.5**	.29	.45*
Age			.08	.13	.01	.36*	.04
Digit Span				.63**	.5**	.57**	.37*
Sorting Task					.52**	.5**	.43*
Interference Task						.38*	.33
EyesTest							.28
Control (n=32)	FSIQ	Age	Digit Span	Sorting Task	Interference Task	EyesTest	CCC
FSIQ		.09	.45**	.29	.33	.19	.13
Age			.39*	-.16	.21	.25	-.13
Digit Span				.42*	.27	.38*	-.01
Sorting Task					.16	.19	-.09
Interference Task						.39*	.04
EyesTest							.09

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

Table 3b. Partial Correlation Coefficients between ToM, social verbal communication, and EF variables in both groups controlling for FSIQ and age.

ASD (n=32)	Digit Span	Sorting Task	Interference Task	EyesTest	CCC
Digit Span		.41*	.39*	.46***	.11
Sorting Task			.41*	.35	.22
Interference Task				.41*	.16
EyesTest					.14
Control (n=32)	Digit Span	Sorting Task	Interference Task	EyesTest	CCC
Digit Span		.45**	.08	.27	-.03
Sorting Task			.10	.19	-.17
Interference Task				.32	.03
EyesTest					.11

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

Table 4. Hierarchical regression analysis for ToM scores.

Predictors	EyesTest	
	β	ΔR^2
Step 1		.064*
Group	-.25*	
Step 2		.128**
FSIQ	.24	
Age	.27	
Step 3 EF		.19**
Digit Span	.33*	
Interference Task	.22	
Sorting Task	.18	
R^2		.383**
F test		5.78***

Note. *p <. 05, **p < .01, *** p < .001