Hot and cool executive function and its relationship to theory of mind in children with and without autism spectrum disorder

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Abstract

Previous research has clearly demonstrated that Autism Spectrum Disorder (ASD) involves deficits in multiple neuropsychological functions, such as Executive Function (EF) and Theory of Mind (ToM). A conceptual distinction is commonly made between cool and hot EF. In ASD, continued attention has been paid to the cool areas of executive dysfunction. Cool EF has been strongly related to ToM but research has not taken into account the association between hot EF and ToM in ASD. The present study investigates the associations between hot and cool EF and ToM in 56 school-aged children with ASD and 69 controls on tasks tapping cool EF (i.e. working memory, inhibition, planning), hot EF (i.e. affective decision making, delay discounting), and ToM (i.e. mental state/ emotion recognition and false belief). Significant group differences in each EF measure support an executive dysfunction in both domains in ASD. Strong associations between delay discounting and ToM mental state/ emotion recognition are reported suggesting that hot EF makes a unique contribution to ToM above and beyond cool EF in typical development and ASD. This study improves understanding of the profile of higher-order cognitive deficits in children with ASD, which may inform diagnosis and intervention.

Key words: Hot and Cool Executive Function, Theory of Mind, ASD

Introduction

Autism Spectrum Disorder (ASD) is a multifaceted neurodevelopmental disorder that significantly impairs children's verbal and nonverbal communication, social interactions, and behaviours (Diagnostic and Statistical Manual of Mental Disorder—DSM-5, American Psychiatric Association, 2013). In addition to the core symptoms, deficits in Executive Function (EF) are common in ASD across the lifespan (Hill, 2004) and have been conceptualised as an associated neuropsychological feature present in several ASD samples (Geurts et al., 2014b; Kenworthy et al., 2008). EF refers to a set of high-order, cognitive and affective control processes that account for future-oriented and goal-directed behaviour (Gioia et al., 2002). EF is suggested to control, and organise one's cognitive activity during problem solving as well as contribute to learning social knowledge (Anderson, 1998). Proponents of the executive dysfunction theory of ASD claim that the symptoms manifested within the spectrum arise from early EF disruptions (Penning ton, & Ozonoff, 1996; Russell, 1997; Russo et al., 2007), and that these are likely to have substantial indirect effects on Theory of Mind (ToM). ToM refers to the ability to infer mental states and is another core cognitive domain that is often impaired in ASD (Tager-Flusberg, 2007). In fact, EF has been frequently associated with the acquisition of ToM across childhood (Rogers et al., 2007). This article presents an empirical investigation that aims to expand on the executive functioning of children with ASD and to further explore the link between ToM and EF in children with and without ASD.

EF was traditionally viewed through a purely cognitive lens that is elicited under relatively abstract, decontextualised, non-affective conditions. However, developmental theorists suggested that EF should be conceptualised as a broader construct, since it also includes affective control processes ("hot processes") (Zelazo and Müller, 2002). Building on the initial “hot-cool systems” distinction as proposed by Metcalfe & Mischel (1999) proposing that hot processes are emotional influences on behaviour controlled by cool EF processes, Zelazo and Müller (2002) suggested a similar, yet fundamentally different, construct of EF that distinguishes between "hot" and "cool" processes. These hot EF processes are different from the cool EF processes but coordinate with them, according to each task’s demands. Hot EF aspects involve top-down processes operating in emotional or motivational situations (hot tasks), while cool aspects of EF involve top down processes operating in affectively neutral contexts (cool tasks). Hot EF processes are evoked under motivationally significant, affective conditions such as delay discounting (i.e. the tendency to choose more immediate, smaller rewards) and affective decision making (i.e. mental processing occurring on the selection of one or more possible options under risk where one employs both rational and emotional processes). In contrast, cool EF includes processes such as inhibition, working memory, and planning, evoked under relatively abstract, non-affective situations (Zelazo, & Carlson, 2012). Relative to the abstract, decontextualised cool EF tasks, hot EF measures have meaningful rewards and losses for the participants. Thus, the affective salience of the situation and the associated cognitive processes distinguish cool and hot EF tasks. The most widely used measures of hot EF are Gambling Tasks, the Marshmallow Test or Delay Discounting tasks (Zelazo, & Carlson, 2012). Although hot and cool EF can be dissociated in lesioned brains, they typically work together as part of a more general adaptive function (Zelazo & Müller, 2002). The hot and cool EF distinction model was used in the present study as it has been proposed to shed more light on the roles of specific EF deficits in developmental disorders (Zelazo, & Carlson, 2012).

Cross-sectional studies on children and adolescents with ASD have consistently revealed significant deficits in cool EF such as working memory (Alloway et al., 2009; Geurts et al., 2014a), inhibition (Christ et al., 2007; Happé et al., 2006) and planning (Kimhi et al., 2014; Verté et al., 2005) compared to typically developing peers (for a review see Hill, 2004). Research into hot EF among participants with ASD is relatively scarce and has mainly focused on older adolescents and adults. Studies employing the Iowa Gambling task (IGT; Bechara et al., 1994) to assess affective decision making among adolescents and young adults with ASD have produced contradictory findings; with some reporting poorer performance relative to a control group (De Martino et al., 2008; Yechiam et al., 2010) and others indicating similar levels of performance between adolescents and young adults with ASD and typically developing peers (Johnson et al., 2006). Very little is known about affective decision making in school-aged children with ASD, with one study (South et al., 2014) suggesting that school-aged children (8-16 years) with ASD demonstrated significantly better performance on the IGT than controls and another (Faja et al., 2013) reporting comparable performance of younger children with ASD (6-7 years) to the control group on the Children's Gambling task (Kerr, & Zelazo, 2004). Finally, with regards to delay discounting ability, only two studies to date have examined delay discounting in children and adolescents with ASD comparing them to ADHD and typically developing peers (Antrop et al., 2006; Demurie et al., 2012). Both studies reported no differences in the performance of participants with ASD compared to typically developing peers in tasks assessing choices for either small, instant rewards or large, delayed rewards. Delay discounting deficits were only found in the ADHD group. The extent to which both hot and cool EF are affected in ASD is difficult to determine from the existing literature, as no study to date has addressed the levels of both hot and cool EF in school-aged children with ASD.

Research on typical and atypical development has consistently associated EF with the acquisition of ToM in early childhood. According to the emergence account, EF is a necessary condition for the acquisition of ToM (Moses, 2001). Less is known about the EF-ToM relation in school-aged children with and without ASD. Theoretically, it could be possible that EF and ToM are intertwined only in early childhood when both abilities emerge, with EF scaffolding the emergence of ToM mechanisms (Bock et al., 2015) as shown by relevant studies (Carlson, & Moses, 2001; Sabbagh et al., 2006). A recent meta-analysis in typical development by Devine and Hughes (2014) has indeed shown a moderate association between cool EF (working memory, planning, inhibition, and cognitive flexibility), selective hot EF aspects (delay of gratification) and ToM false belief in early childhood. As this theoretical account does not explain potential EF-ToM relations later in development, (i.e. school age), another theoretical position suggests that EF and ToM are "inextricably linked" across the life span as both abilities interrelate through "cognitive competencies and performance factors" (share overlapping peripheral task demands) (Apperly, Samson, & Humphreys, 2009). The study of the EF-ToM relation beyond the preschool period has recently received growing attention with results showing significant correlations in typical development (Austin et al., 2014; Bock et al., 2015; Im-Bolter et al., 2016) but has mainly focused on cool EF aspects.

ToM has been consistently found to be impaired in ASD samples in measures tapping the attribution of false belief knowledge (Begeer et al., 2012; Sobel et al., 2005) and mental state/ emotion recognition (Brent et al., 2004; Holt et al., 2014). Evidence about the relationship between EF and ToM in ASD is limited and is more focused on the preschool period as well. Pellicano (2007) indicated that ToM and cool EF (i.e. planning, cognitive flexibility, and inhibition) were significantly correlated in young children (4-7 years) with ASD even after partialling out the effects of chronological age, verbal, and non-verbal ability. In a subsequent longitudinal study of two time points (followed after 3 years), Pellicano (2010) indicated that the cool EF abilities (planning, cognitive flexibility, and inhibition) of children (4-7 years) of the first time point were a significant predictor of the changes in children's ToM skills at the second time point (over and above the variance of age, verbal, and non-verbal ability) suggesting that EF contribute to the ToM mental understanding development in ASD. Only a few studies have investigated the relation between ToM and cool EF in school-aged children with ASD. For example, Joseph and Tager-Flusberg (2004) indicated that ToM tasks (location change and unexpected content false belief) were significantly correlated to deficits in cool EF such as inhibition, planning, and working memory in school-aged children and adolescents (5-14 years) with ASD. Similarly, Ozonoff et al. (1991) found a significant relation between cool EF impairments (planning, cognitive flexibility, and working memory) and ToM (knowledge, false belief) scores in children and young people (8-20 years) with ASD. Despite hot EF being controlled by the ventromedial and orbitofrontal regions which are suggested to also regulate social behaviour (i.e. ToM) (Chan et al., 2008; McDonald, 2013), there is no study in ASD to date which has investigated whether hot EF and ToM share such a significant relation and how they may interact within the cognitive profile of school-aged children with ASD. Due to minimal knowledge regarding the hot EF-ToM relation, our study will be exploratory and specific predictions about such relation cannot be stated. The present study will hopefully enhance our understanding of the higher-order cognitive deficits that underpin social cognition problems (such as ToM deficits) in ASD.

Current Study

The current study had two main objectives:

The first aimed to investigate group differences in hot and cool EF in school-aged children with ASD relative to typically developing peers. Research on EF deficits in ASD has mainly focused on cool EF, failing to address hot EF measures. Thus, the current study sought to extend the investigation of EF differences between school-aged children with and without ASD by employing a more extensive battery of both cool and hot EF tasks in comparison to previous studies (Bock et al., 2015; Geurts et al., 2014a). The hot and cool EF model could shed more light on the cognitive profiles of intact and impaired EF abilities in ASD. Moreover, as the limited research on hot EF in ASD has mainly focused on early adolescence and adulthood (Antrop et al., 2006; Demurie et al., 2012; Faja et al., 2013), the present study explored group differences in both cool and hot EF in school-aged children addressing the age gap in the literature. We hypothesised that ASD participants would exhibit a poorer performance on tests of cool EF. We sought to determine whether participants with ASD, in contrast to controls, would exhibit a lower level of performance on hot EF measures as well.

The second aim of the present study was to explore the association between hot and cool EF and ToM abilities in school-aged children with and without ASD. School age (middle childhood and early adolescence; 7-12/13 years) is a crucial period of rapid developmental and cognitive change where children have to define and understand both their own sense of self and their sense of others (Siegel, 2013). Thus despite the significant evidence from early childhood, the extension of the EF-ToM relation to school age needs to be examined further in order to provide a solid ground for future longitudinal and training studies that could more precisely identify the underlying mechanisms linking EF and ToM. Traditionally, research on the EF-ToM relation has mainly employed cool EF tasks. The distinction between cool (cognitive) and hot (affective) EF led Zelazo et al. (2005) to suggest that ToM may be more strongly related to hot EF than cool EF. Based on evidence from early childhood (Devine, & Hughes, 2014), we hypothesised that hot EF would still associate with ToM in school age and attempted to specifically examine whether ToM performance could be predicted by hot EF performance after controlling for potential co-variates and cool EF in children with and without ASD.

Method

Participants

Fifty six children (56) with an official diagnosis of ASD (52 males) (*M*=9.98 years, *SD*=1.9) and sixty nine (69) controls (*M*=9.64 years, *SD*=1.58) (60 males) aged 7-12 years old were recruited from thirty mainstream and special education schools to participate in the present study. All ASD participants were high functioning (IQ > 70), held an official clinical diagnosis by a qualified clinician using DSM-IV criteria (American Psychiatric Association, 1994) and qualified for a “broad ASD” on the Autism Diagnostic Interview/Autism Diagnostic Interview-Revised (ADI/ADI-R; Le Couteur et al., 1989; Lord, Rutter, & Le Couteur, 1994”) and/or the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000) , in accordance to National Institute for Health and Clinical Excellence (NICE, 2011) guidelines. They were also in receipt of a Statement of Special Educational Needs (SEN), a legal document that details the child's needs and services that the local authority has a duty to provide, which specified ASD as their primary need. All clinical records were inspected and any individual lacking detailed information about the official source of diagnosis was excluded from the study. No separate research diagnosis using a diagnostic instrument was carried out as there is high degree of agreement between clinical and research diagnosis (Mazefsky, & Oswald, 2006). Additional exclusion criteria for the ASD group included the presence of a diagnosed psychiatric illness, comorbid conditions (i.e. seizures or colour blindness) and Full Scale Intelligence Quotient (FSIQ) below 70 as determined by the abbreviated version of the Wechsler Intelligence scales (two subtests: vocabulary and matrix reasoning; Wechsler, 1999). Sixty nine typically developing children were recruited from mainstream primary schools (Years 2-Years 6). Typically developing participants were required to have no diagnosis, and no family history of ASD or other mental health disorders, dyslexia or learning disability. Participants were matched for chronological age ($t\ (123) = -1.1$, $p = .29$) and FSIQ ($t\ (123) = .8$, $p = .42$). Ethical approval for the study was obtained and all participants' parents/carers gave written informed consent (consistent with the Declaration of Helsinki) in compliance to the University Research Ethics Committee. Table 1 shows descriptive characteristics (means and standard deviations) of participants of both groups.

[Table 1 should be placed here]

Measures

Cool Executive Function

Inhibition. The 'R' and 'P' version of the Go/No-Go paradigm (Mueller, & Piper, 2014) was used in the present study to assess participants' response inhibition. An image of either the letter P or letter R appeared in the centre of the screen (for 1500 milliseconds) on a black background. Participants were then instructed to press the button only when the letter P was shown (Go trials) and to avoid pressing it for the letter R (No-Go trials). On the second block of trials, the pattern was reversed and the participants were asked to press the button when the letter R appeared (Go trials) and to avoid pressing it when P was presented (No-Go trials) this time. There was no feedback provided after a correct or incorrect response. Before each block, participants first completed 10 practice trials followed by the actual 320 test trials. In order to measure participants' response inhibition, the proportion of incorrect No-Go trials was recorded. Lower scores indicated better performance.

Planning. Participants' planning ability was measured by the Tower of London (ToL) task (Shallice, 1982). As a practice, participants were presented with three 3-move problems, followed by the 12 actual trials of the original problem set (two 2-move tasks; two 3-move tasks; four 4-move tasks; and four 5-move tasks). Following the procedure of Monks et al. (2005) and Poland et al. (2015), successful performance required participants to solve each problem moving only one bead each time and in the number of moves required; participants were given two minutes to complete each problem. The task was stopped when the participant completed all problems or failed two of them consecutively. In terms of the scoring, we measured the number of problems each participant completed successfully. One point was given to participants if they completed the problem successfully and 0 points if they failed to complete the problem. Scores ranged from 0 to 12.

Working Memory. The digit span forward and backwards subtests from the Wechsler Intelligence Scale for Children-3rd edition were employed to measure participants' verbal working memory (WISC-III; Wechsler, 1991). Participants were asked to recall the sequence presented by the researcher (at a rate of one number per second) in the exact same order. In the backwards digit recall task, the series of numbers should be repeated in reverse order. If participants responded successfully to all trials (4) within a block, the researcher proceeded to the next block. Each block included 2 trials at each span length. In terms of scoring, participants were awarded 1 point for each correct trial and the task was terminated when the participant failed both trials at any given span length. The sum of the points awarded for both the forward and backward subtest created a working memory score which was then converted into a standardised score.

Hot Executive Function

Affective Decision Making. A modified computerised version of the IOWA gambling task (IGT; Bechara et al., 1994) was employed to measure participants' affective decision making. Participants were presented with four decks of cards (A, B, C, and D) and were told they should select a card from any of the four decks each time. Decks A and B were equivalent in terms of overall net loss, whereas decks C and D were equivalent in terms of overall net winning. For each card selection, the wins and losses were set in a way that in every block of 20 cards from Decks A or B there was a potential total gain of £1,000, interrupted by potential losses up to £1,250. Losses were less frequent but of a larger magnitude in deck B whereas in Deck A losses were more frequent but in smaller amounts. For Decks C and D, the wins for each block were £500 totally while the potential net losses £250. In Deck D losses were less frequent and of higher magnitude relative to those in Deck C. Thus, Decks A and B were equally "disadvantageous" relative to Decks C and D that were equally "advantageous". We measured whether participants de mainly more advantageous or disadvantageous decisions. Based on the approach used by Verdejo-Garcia et al. (2006), scores were calculated by subtracting the number of disadvantageous choices (decks A and B) from the number of advantageous choices (decks C and D) divided then by the total number (n= 100) of trials.

Delay Discounting. In line with previous research studying hot EF (Hongwanishkul et al., 2005; Prencipe et al., 2011), the Delay Discounting task was used in the present study in a computerised version to assess participants' ability to discount rewards (Richards et al., 1999). This task originally included the forced-choice between different amounts of money after different delays or with different chances. However, as the task was being given to school-aged participants it was decided to modify it and completely remove the probability questions. Participants were told that they had to choose (hypothetically) between an immediate amount of money or £10 available after a delay. The test consisted of about 70 such questions (i.e. (a) Would you rather have £10 for sure in 30 days or (b) £2 for sure right now?). The amount of immediate money was adjusted until the participant was indifferent between the two choices (random adjusting procedure; Richards et al., 1999). For every participant, this indifference point signified the effective value of the delayed large reward relative to an immediate amount of money (Richards et al., 1999). Delay discounting was determined by five delays (0, 10, 30, 180, and 365 days later). In terms of scoring we followed the procedure described in Myerson et al. (2001), where the indifference points were used to estimate delay discounting. Thus, indifference points were established within participants and were plotted against time (delay). Indifference points and delays were normalised, by expressing indifference points as proportions of the amount of the maximum delayed reward (£10) and the delays as proportions of the maximum delay (365 days). These normalised values were used as the x (delay) and y (indifference points) axes in order to plot the discounting function. Separate trapezoids were then created by drawing vertical lines from each data point on the x axis. The formula $(x_2-x_1) \cdot [(y_1 + y_2) / 2]$ was used to calculate the area of each trapezoid. The areas under these discounting curves (AUC) were calculated by summing the resulting trapezoids. Lower scores indicated better performance.

Theory of Mind

False/no false belief. In order to measure participants' false and no false belief understanding, the Sandbox Task (Begeer et al., 2012) was used. In the first *false belief* condition, participants were told that this task was about a father and a daughter (Sanne) planting flower bulbs in a sandbox. Participants were asked to listen to the storyline carefully while they could read along from the paper if they wished. The researcher showed the participants the picture of a sandbox and told them the father decided to bury the flower bulb at the location of the cross. When the father went away to bring a watering can, Sanne decided to move the flower bulb and bury it in a different location. Before asking the false belief question, the researcher asked whether participants had a good look at the pictures and remembered where each character (Sanne and her dad) placed the flowerbulb, in order to ensure that they have the requisite attentional or memory capacities necessary to demonstrate their theory of mind knowledge (control question). The researcher then asked the participants one false belief question: "When Sanne's dad comes back with the watering can where will he give water to the flower bulb? You have to draw a cross". On the second no false belief condition participants were shown again the same picture and were told that Sanne's dad decided to bury the flower bulb at the location of the cross. However, when dad went away this time Sanne decided to bury a stone at another location in the sandbox. Before asking the no false belief question at this condition, the researcher asked whether participants had a good look at the pictures and remembered where dad placed the flowerbulb and where Sanne buried the stone, in order to ensure that they have the requisite attentional or memory capacities necessary to demonstrate their theory of mind knowledge. The researcher then asked the participants the following no false belief question: “When Sanne’s dad comes back with the watering can where will he give water to the flower bulb? You have to draw a cross”. In terms of scoring, the difference between the original hiding location of the flower bulb (0 cm) and the location where participants indicated dad would look for it was measured (in centimetres). If participants indicated a location towards the direction of Sanne’s hiding location of the flower bulb (6,3 cm) in the false belief version, or the stone (6,3 cm) in the no false belief version, they received a positive bias score. If participants indicated a location in the opposite direction of the flower bulb or the stone, to the right of the original hiding location, they received a negative bias score. Two ToM variables were created based on the false and no false belief conditions. Lower scores indicated better performance. It was ensured that both groups understood the complex instructions for the present task as the inspection of their verbal IQ demonstrated similar performance [$t\ (108) = 3.08$, $p < .001$]. Only the false belief task was used as a dependent variable in the subsequent analysis whilst the no false belief task served as an inclusion measure. More specifically, children were excluded from the ToM analysis if they demonstrated a deviance higher than 10cm on the no false belief task. Participants that were more deviant on the no false belief task did not likely understand the task or attend to the instructions. Introducing control measures in ToM tasks ensures that responses on the false belief tasks indicate participants’ actual representational theory of mind knowledge (Sobel, & Austerweil, 2016). This paradigm was employed in order to avoid ceiling effects as it is age-appropriate for school-aged children (the classic false/no false belief task is only appropriate for young children 3-6 years). Furthermore, as the object is buried and reburied in the sandbox, a continuum is created between locations in contrast to the categorical approach of the classic false/no false belief task that has been found to sometimes omit the subtle variance in false belief reasoning at different ages (Bernstein et al., 2011).

Emotion recognition

The Reading the Mind in the Eyes test (children's version; Baron-Cohen et al., 2001) was used to assess mental state/ emotion recognition. This task was chosen as it is a widely used ToM test that measures the ability to decode the feelings and thoughts of others from the eyes. The Reading the Mind in the Eyes test has been evaluated in more than 250 studies and has demonstrated to have good reliability (Fernandez-Abascal et al., 2013; Vellante et al., 2013). The test can also be considered an emotion recognition test (Vellante et al., 2013). It consists of photographs of the eye regions of 28 faces. Participants were asked to make a choice between four words presented at the bottom of the page on which each picture appeared, choosing the one that best described what the person of the photograph was feeling or thinking. Successful performance required participants to select the correct mental and emotional state. Participants were asked to choose one of the terms even if they said that any term was quite right, thus conforming to a forced-choice procedure. One point was given to each correctly reported response.

Statistical Analysis

Statistical analyses were performed using SPSS-23®. Variables were checked for normality and homogeneity assumptions of parametric tests. No outliers were found. Three participants (1 typically developing and 2 with ASD) were excluded from the ToM analysis as they deviated more than 10cm on the no false belief task. Multivariate analysis of covariance (MANCOVA; adjusted for age and FSIQ) and follow up ANCOVAs (adjusted for age and FSIQ) were conducted to perform between-group comparisons. Post-hoc tests were corrected for multiple comparisons using Bonferroni correction. Pearson's correlations were performed to examine the preliminary relation between EF and ToM measures within the whole sample. Finally, the extent to which hot EF scores would show a unique contribution to ToM independent of ASD and above and beyond the cool EF and control variables (FSIQ and age) was investigated by performing linear hierarchical regression analysis, with cool EF *(go/no-go, digit span, ToL scores)*, control variables (*age & FSIQ*) and ASD diagnosis entered in Block 1, and hot EF variables *(delay discounting* and *IGT scores*) entered in Block 2. In addition, we examined whether the association of hot EF variables to ToM was stronger in either controls or ASD, by including hot EF X ASD diagnosis interaction terms in Block 3, computed from the cross-product of effect-coded ASD (-1=Autistic, +1=Control) and the centred hot EF scores (Aiken and West, 1991). A small amount of missing data was evident for variables to be examined in the regression analysis (<2.5% for all variables) with missing values imputed using expectation maximization estimation. No violations of multivariate assumptions for these variables were found. All tests were two-tailed and statistical significance was set at $p < .05$.

Results

Group Differences

Multivariate analysis of covariance (MANCOVA) showed that the performance of the ASD group on EF measures was poorer overall than that of the control group (λ = .69, F (5, 109) = 9.47, p < .001, η^2= .3). Post hoc follow up ANCOVAs revealed significant group differences in participants' performances both on cool EF: Go/No-Go (F (3, 121) = 15.72, p < .001, η^2= .12), Digit Span (F (3, 123) = 26.46, p < .001, η^2= .18), ToL (F (3, 122) = 5. 73, p = .018, η^2= .05) and hot EF tasks: IGT (F (3, 122) = 5.48, p = .021, η^2= .04) and delay discounting (F (3, 121) = 11.44, p = .001, η^2= .09) (see Table 2 for means and standard deviations). The ASD group performed significantly worse in each hot and cool EF task relative to the control group.

ANCOVAs were also run to investigate group differences on the ToM measures. Significant group effects were found both in the false belief measure F (3, 121) = 45.39, p < .001, η^2= .28) and Eyes Test (F (3, 123) = 49.67, p < .001, η^2= .29). ToM skills of participants with ASD were significantly lower than the typically developing peers (see Table 2 for means and standard deviations). The ASD group's performance was significantly lower in both ToM tasks compared to the control group.

[Table 2 should be placed here]

Relations between EF and ToM

Correlational analysis in the whole sample (see Table 3) showed several significant associations between EF and ToM measures. Specifically, ToM false belief performance was significantly correlated to all cool EF measures and hot Delay Discounting, whereas performance on the Eyes Test was related to all EF measures, both cool and hot. Supplementary correlational analysis partialling out the effects of control variables (age and FSIQ) was conducted again. The ToM false belief measure remained significantly related to all cool EF and hot Delay Discounting, whereas the Eyes Test remained significantly associated only with Digit Span, Go/No-Go, and Delay Discounting (see table 3). [Table 3 should be placed here]

The relation between EF and ToM was further investigated by running two hierarchical multiple regression analyses in order to assess the extent to which hot EF scores predicted ToM (*false belief* and *Eyes Test scores*) independent of ASD diagnosis and over and above cool EF as well as control variables (age & FSIQ), and to examine whether the association between hot EF and ToM was stronger in ASD participants compared to controls. Dependent variables included the Eyes Test and false belief measures.

Full results of the hierarchical regression analysis are presented in Table 4. These show that the first block introducing age, FSIQ, cool EF and ASD contributed significantly to the variance of the ToM false belief ability, F (6, 118) = 9.99, $p <$ .001, explaining 34% of the variance. However, neither block 2 variables of Hot EF scores nor block 3 variables of Hot EF X ASD diagnosis interaction terms contributed significant additional variance.

Regarding ToM mental state/ emotion recognition, control variables, ASD and cool EF explained 39.2% of the variance in Eyes Test scores [F (6, 118) = 12.70, $p < .001$]. For hot EF variables entered in block 2, the total variance explained rose to 42.7%, representing a significant increase of 3.4% [F (2, 116) = 3.48, p =.034] additional variance explained. The Hot EF X ASD interaction terms entered in block 3 explained no significant additional variance. Eyes Test scores were significantly predicted by Go/no Go scores (p = .03), delay discounting (p = .015) and ASD ($p < .001$).

[Table 4 should be placed here]

Discussion

This study compared a relatively large group of school-aged children with ASD to typically developing peers using a number of cool and hot EF tasks. It also investigated the relation between both EF constructs and ToM in school-aged children with and without ASD. Participants with ASD demonstrated poorer performance in all EF and ToM domains suggesting that the reported group differences reflect a universal ToM and EF impairment in both hot and cool systems in ASD. Furthermore, our findings not only replicated the well-established relation between cool EF and ToM but also demonstrated a predictive relation between hot EF (delay discounting) and ToM mental state/ emotion recognition, prompting questions of how these seemingly distinct constructs are related. This is the first study to date to report that a hot EF aspect is a significant predictor of ToM mental state/ emotion recognition above and beyond cool EF in school age and that children with ASD exhibit hot EF impairment, which are likely to contribute to their deficits in ToM.

School-aged children with ASD presented significant impairments in each hot and cool EF task relative to matched typically developing children of the same age. The present findings of deficits in cool EF are consistent with results of previous studies reporting deficits in working memory (Alloway et al., 2009; Geurts et al., 2014a), planning (Geurts et al., 2014a; Hill, 2004) and response inhibition (Hill, 2004; van Eylen et al., 2015) in participants with ASD of the same age range. There is thus clear evidence that individuals with ASD experience deficits in cool EF domains.

In terms of hot affective decision making, our results are in line with previous studies (De Martino et al., 2008; Yechiam et al., 2010) that have demonstrated deficits in adolescents and young adults with ASD and further extend this to a younger age ASD group. The larger sample size and different IQ level of our ASD participants could have possibly accounted for the results that contradicted those of Johnson et al.'s (2006), Faja et al.'s (2013), and South et al.'s (2014) studies, despite the IGT also being used. The limited sample sizes (Johnson et al., *n=29*; Faja et al., *n=40*) do not usually allow for the detection of significant differences while the superior IQ scores (10 points higher) of South et al.'s (2014) participants could possibly explain discrepancies in findings. These inconsistencies though highlight the need for future studies investigating affective decision making in school-aged children with ASD.

Regarding the ASD deficits we found in hot delay discounting, our results are not consistent with those of Antrop et al. (2006) and Demurie et al. (2012) who found that ADHD school-aged children, but not school-aged children with ASD, chose smaller, immediate rewards over large delayed rewards more than the control group. Results contradicting Demurie et al. (2012) were quite surprising, as these researchers also employed the AUC scoring approach to a similar age range of ASD participants (8-16 years). However, their delay discounting task addressed much higher reward magnitudes (such as 0€, 5€, 10€, 20€ and 30€) and shorter delay values (i.e. now, tomorrow, the day after tomorrow, 1 week, 2 weeks) than in our task. It seems that the discounting rate is a decreasing function of the size of the delayed reward (rate decrease as the amounts offered increase) (Kirby, & Maracovic, 1996). Antrop et al. (2006) used a less demanding task where participants had to choose between an immediate small reward (1 point) after a 2-second delay and a larger delayed reward (2 points) after a 30-second delay. Thus participants with ASD may exhibit responses similar to control group discounting trajectories if the monetary rewards are significantly high or the time delays are very short in magnitude. Our results support an impairment in both hot and cool EF systems across school age in ASD expanding the executive dysfunction to not only cool EF but hot processes such as affective decision making and delay discounting as well.

With regards to ToM deficits, the reported impairments in false belief skills are consistent with previous findings showing deficits in such skills in young children with ASD (Kimhi et al., 2014; Pellicano, 2007) and indicate that ToM difficulties persist in school-aged children with ASD. In relation to ToM mental state/ emotion recognition, our results revealed that participants with ASD presented significant differences relative to the control group and contradict a previous study that assessed ToM using mental state/ emotion recognition scores in pre-school children with ASD (Kimhi et al., 2014). More specifically, Kimhi et al. (2014) showed that pre-school children with ASD (age: 5 years) performed successfully in tasks requiring recognition of basic emotions (happy/sad) relative to the control group. The Reading the Mind in the Eyes test used here assesses a more sophisticated ability, namely to recognise or infer another's emotional mental state. Such ability is fundamental to understanding and effectively communicating with other people when interacting socially. Our results indicated that this ability is impaired in school-aged children with ASD and are in line with previous research (Golan et al., 2007; Rieffe et al., 2000) suggesting that the emotion recognition of children with ASD is disrupted when processing high-order, complex or atypical emotions.

Our correlational and regression analysis results showed that EF and ToM are strongly associated in school age beyond their emergence in early childhood. In line with previous studies showing cool EF-ToM associations in young and school-aged children with and without ASD (Carslon, & Moses, 2001; Pellicano, 2007; Kimhi et al., 2014; Ozonoff et al., 1991), we found that ToM mental state/ emotion recognition was predicted by cool EF (inhibition) overall. Participants who performed better in the inhibition task could more easily disengage from their own emotional states or suppress irrelevant ones, and subsequently infer advanced empathising skills for another's emotion. During middle childhood (7-11/12) children are in greater need of their EF abilities when facing advanced forms of knowledge and widening social horizons through sophisticated social interactions with peers (Del Giudice, 2014). Our results indeed show that in ToM thinking across school age it seems necessary to *inhibit* one's own perspective when socially interacting, in order to infer all the relevant interactive pieces into a coherent framework.

Our findings confirm earlier research suggesting that hot EF does indeed relate to ToM performance. The hot EF aspect of delay discounting predicted ToM mental state/ emotion recognition over and above cool EF and control variables in school-aged children with and without ASD. ToM is a multifaceted function involving not only beliefs, desires and emotions but also processes associated with the successful management of long-term goals (Korkmaz, 2011). Thus, the capacity to disengage from the present while considering more long-term goals could associate with the way one engages with emotional states. Stolarski et al. (2011) suggest that emotional functioning plays an important role in the development of a temporal perspective. For instance, the ability to balance decisions and their future consequences is associated with mental state/ emotion recognition ability in the sense that effective emotional functioning allows for more effective balancing between temporal perspectives. Delay discounting is a fundamental aspect of future temporal perspective taking and plays an important role in the development of future-oriented behaviours (Zimbardo, & Boyd, 2008). This could also explain the significant associations between individual differences in delay discounting and mental state/ emotion recognition. Delay discounting engages not only decisional processes but also affective emotional mechanisms, raising the need to empirically investigate how discounting rate is actually linked to emotional functioning across the lifespan in typical development and ASD.

It should be noted that the hot EF x ASD interaction contributed no significant additional variance as generally interactions are notoriously underpowered for observational data (i.e. usually non-significant in all but very big samples); thus a more rigorous examination of any hot EF x ASD interaction would require a larger sample size. However, hot EF was associated to ToM impairment above and beyond any influence of cool EF, and the ASD participants demonstrated impaired hot EF. This could suggest that hot EF may be a key mechanism underpinning deficits in ToM for high-functioning children with ASD. This finding requires further replication with a larger sample.

This study investigated the associations between hot and cool EF and ToM in school-aged children with and without ASD. The significant group differences in each hot EF task followed by a significant association between hot delay discounting and ToM mental state/ emotion recognition should be considered in light of the limitations of this study. First, due to the convenience sampling approach followed, the children that participated in the current study (high-functioning group of ASD children) may not represent the broader ASD population. An additional limitation was also the lack of a validated screening tool to support the provided clinical diagnostic reports of ASD. Moreover, although this study provided a more advanced insight into the fractionated hot/cool EF model in ASD, it only included 7 to-12-year-old school-aged participants;

hence it remains to be found whether these results could be generalized to younger children, adolescents, and adults across the autism spectrum functioning levels. Finally, as the present study was the first to report such a relation, the findings need to be interpreted cautiously. Specifically, as hot EF delay discounting significantly predicted only one of the two ToM measures addressed (Eyes Test), clear conclusions about the role of hot EF to the wider ToM context cannot be drawn. It should be noted that the Reading the Mind in the Eyes test is a task tapping mostly emotion understanding aspects, while the Sandbox task is a more cognitive measure of understanding beliefs. Our results showed that hot EF presented a predictive relation only with the Eyes Test that can be argued to measure a more affective aspect of ToM cognition. The failure to demonstrate a hot EF- Sandbox task association could be cautiously explained in the basis of the underlying affective nature of hot EF by definition, suggesting that hot EF is elicited under motivationally or emotionally significant situations (such as inferring emotional states in the Eyes Test). It could be possible that cognitive and affective ToM are dissociated and that hot ToM might correlate more strongly with hot EF. However, as this issue goes beyond the scope of the present study, it is worth questioning in future research whether these two distinct domains of EF (hot and cool) correspond in reality to separate ToM measures tapping different abilities. Both ToM measures we addressed here tap only particular aspects of ToM (either purely cognitive or affective cognitive) and cannot be considered the only essential ToM measures. Follow-up research should therefore consider investigating such relations addressing several other varied ToM tasks such as second-order ToM (Perner, & Wimmer, 1985), the strange stories (Happé, 1994) or the Faux Pas test (Baron-Cohen et al., 1999). Furthermore, the exact relation between ToM mental state/ emotion recognition and delay discounting is difficult to determine as our data do not provide evidence about directionality of the relation. In the light of the conceptual framework presented above, mental state/ emotion recognition seems to contribute to the development of temporal dimensions such as delay discounting. On the other hand, our regression models revealed that delay discounting predicted ToM mental state/ emotion recognition over and above control variables. The focus on specific temporal dimensions (i.e. delay discounting) may thus influence the development or use of emotional abilities. This unclear directionality could be further investigated by future studies using longitudinal approaches that could facilitate the understanding of such complex causal relations. Finally it should be noted that our correlational pattern indicated (weak) associations between hot and cool aspects in school age. Although this evidence is in line with previous studies in typical development (Hongwanishkul et al. 2005; Hooper et al., 2004; Prencipe et al., 2011), it raises questions about the independency of the two constructs. As generally data from correlational studies or factor analyses/ structure equations models of hot and cool EF are equivocal supporting either a single or dual factor model, it could be argued that there could be "some shared cognitive processes" between hot and cool EF components (Welsh & Peterson, 2014). It is important though at this point to also consider the different predictive patterns of each domain as hot and cool EF may predict different social/ developmental outcomes. The degree to which each domain is related or not to different outcomes could support somehow the notion for separate (or unified) cool and hot EF (Welsh & Peterson, 2014). In any case, future longitudinal studies across childhood and adolescence are warranted as they will hopefully better highlight the brain structure of cool and hot EF.

In conclusion, the present study showed a ToM and EF impairment in both hot and cool systems in ASD and that hot and cool EF are associated with selective ToM mechanisms in school-aged children with and without ASD. Further studies need to explore the organisation of cool and hot EF (from childhood to adulthood) and their relation to various facets of ToM. The present findings though highlight that considering the role of both hot and cool EF in association with ToM in individuals with ASD may aid in gaining a greater understanding, not only of the higher-order cognitive deficits underlying difficulties with social interaction for the ASD population, as well as the conceptualisation of these overlapping yet separate constructs. Our findings highlight the need to assess hot and cool EF in clinical practice and may hopefully aid in enhancing diagnosis or better informed intervention projects taking into account both hot and cool EF impairments.

Conflicts of Interest: None.

Ethical approval: "All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards."

Informed consent: "Informed consent was obtained from all individual participants included in the study."

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Tables

Table 1. Participants' characteristics

	Group	
	ASD	Control
Variable	(*n*=56)	(*n*=69)
Age (in years)		
M (SD)	9.98 (1.9)	9.64 (1.58)
Range	7-12	7-12
FSIQ total score		
M (SD)	97.73 (16.16)	99.91 (14.24)
Range	70-127	72-135

Table 2. Descriptive statistics for EF and ToM measures.

	Group		
	ASD (n = 56)	Control (n = 69)	
Domain and Measure	*M (SD)*	*M (SD)*	p value
Cool EF			
Digit Span	7.36 (2.64)	9.91 (2.90)	<.001
Go/No go	50.80 (15.02)	37.93 (20.34)	<.001
ToL	7.07 (2.11)	7.85 (1.93)	.018
Hot EF			
IGT	-.05 (.18)	.03 (.20)	.021
Delay Discounting	.45 (.21)	.35 (.12)	.001
ToM			
False belief	6.4 (3.62)	3.29 (1.23)	<.001
EyesTest	14.87 (3.36)	18.41 (2.45)	<.001

Table 3. Pearson's Correlation Coefficients among ToM and EF variables.

Measures	FSIQ	Age	DigitSpan	ToL	Go/No-Go	IGT	Discounting	FalseBelief	EyesTest
FSIQ		-.43**	.22*	.23**	-.05	.15	-.05	-.19*	.30**
Age			-.001	.22*	-.09	-.04	-.02	-.03	.01
DigitSpan				.37**	-.17	.26**	-.19*	-.32**	.26**
ToL					-.06	.11	-.10	-.29**	.30**
Go/No-Go						-.20*	-.02	.26**	-.33**
IGT							-.09	-.17	.22*
Discounting								.22*	-.32**
FalseBelief									-.42**

Control for: Age & FSIQ	DigitSpan	ToL	Go/No-Go	IGT	Discounting	FalseBelief	EyesTest
DigitSpan		.32**	-.15	.23	-.19	-.28**	.19*
ToL			.001	.07	-.07	-.23*	.18
Go/No-Go				-.19*	.01	.24**	-.33**
IGT					-.09	-.14	.18
Discounting						.21*	-.32**
FalseBelief							-.37**

Note. *p <. 05, **p < .01. *FSIQ*: Full Scale Intelligence Quotient, *ToL*: Tower of London, *IGT*: Iowa Gambling Task, *Discounting*: Delay Discounting, *Eyes Test*: Reading the Mind in the Eyes

For Go/No-Go, Discounting, and False Belief tasks lower scores suggest better performance, thus the negative values.

Table 4. Hierarchical regression analysis for ToM false belief and Eyes Test scores by group and EF variables

Predictors	False belief		EyesTest	
	β	ΔR^2	β	ΔR^2
Block 1 (Control variables, cool EF and ASD)		.34**		.39**
Age	-.08		.14	
FSIQ	-.16		.3**	
Digit Span	-.04		-.07	
Go/No-Go	.05		-.16*	
ToL	-.14		.09	
ASD	.46**		-.47**	
Block 2 (Hot EF)		.004		.03*
IGT	-.04		.07	
Delay discounting	.046		-.18*	
Block 3 (Hot EF X ASD interactions)		.03		.01
ASD X IGT	-.06		-.03	
ASD X Delaydiscounting	-.03		-.12	
R^2		.37		.44

F test	2.61	1.19

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