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Are executive dysfunctions relevant for the autism-specific cognitive profile?

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Abstract

The role of Executive Function (EF) has been shown to be important for Autism Spectrum Disorder (ASD) but also for other developmental disorders and could therefore not be determined as autism specific. To specify the role of EF in ASD, its relationship to autism associated concepts such as Theory of Mind (ToM) and Weak Central Coherence (WCC) needs to be explored.

Medline- and PsychINFO databases were searched for studies published between January 1990 to December 2019, that included measures of EF in ASD and typically developing controls (TD) in combination with either ToM or WCC. For data analysis a random-effects model was used where the primary outcome measure was Hedges' g for subgroups of EF, ToM and WCC. Moderator analysis regarding Age and IQ was performed via meta-regressions. A moderating effect for age was observed. Also, a correlation analysis investigating the association between EF and ToM was performed. Results were reported according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.

Data came from a total of 42 studies (N, ASD=1546, TD=1206). In all three cognitive domains under study, the ASD group was significantly impaired in comparison to controls. Correlations between EF subdomains and ToM can be categorized as small for the ASD- and the TD group. No moderator effect for IQ could be observed. No publication bias was observed.

This study showed that there is an overall impairment in ASD among all classical cognitive constructs. However, a significant association between EF subdomains and ToM could not be shown, questioning the relevance of EF for the autism-specific cognitive profile.

Zusammenfassung

Die Rolle der Exekutiven Funktionen (EF) hat sich für für Autismus Spektrum Störungen (ASD) als sehr wichtig erwiesen. Gleichzeitig spielen Einschränkungen der EF aber auch bei anderen neurologischen Erkrankungen eine große Rolle und können daher aktuell nicht als spezifisch für Autismus beschrieben werden. Um die Rolle der EF weiter zu spezifizieren ist es notwendig, diese mit anderen Konzepten, welche eindeutig mit Autismus assoziiert sind, wie z.B. Theory of Mind (ToM) und Central Coherence (CC) in Verbindung zu setzen.

Die Datenbanken Medline und PsychINFO wurden nach Artikeln im Zeitraum von Januar 1990 bis Dezember 2019 durchsucht, welche Daten zu EF bei Autisten und einer neurotypischen Kontrollgruppe (TD) in Verbindung mit entweder ToM oder CC untersucht hatten. Für die Datenanalyse wurde ein randomisiertes Effekt Modell genutzt. Der primäre Ergebnisparameter war dabei Hedges g für die EF Subgruppen, sowie ToM und CC. Es wurde eine Moderator Analyse für Alter und IQ berechnet, welche einen Moderator Effekt für das Alter fand, IQ hatte keinen Effekt. Weiterhin wurde eine Korrelations-Analyse für die Variablen EF und ToM durchgeführt. Die Ergebnisse wurden nach den PRISMA Richtlinien in wiedergegeben.

Der Datensatz beinhaltete 42 Studien (N, ASD=1546, TD=1206). In allen drei kognitiven Bereichen, die untersucht wurden, schnitt die ASD Gruppe signifikant schlechter ab, als die Kontrollgruppe. Die Korrelation zwischen EF und ToM ist sowohl in der ASD- als auch in der TD Gruppe als klein zu beschreiben.

Diese Studie zeigt, dass es eine generalisierte Beeinträchtigung bei Autisten im Hinblick auf alle kognitiven Konstrukte gibt. Eine signifikante Korrelation zwischen EF

und ToM konnte jedoch nicht nachgewiesen werden, womit die Relevanz der EF im Bezug auf Autismus eindeutig in Frage zu stellen ist.

Introduction

Autism Spectrum Disorders are neurobehavioral disorders that primarily comprise impairments in the social domain with a focus on interaction, communication and repetitive and stereotypical interests and behaviours (American Psychiatric Association, 2013). The lifetime prevalence for ASD is estimated at 0.9 – 1.1 % worldwide. Data from multiple studies beginning in the year 2000 estimated the median prevalence of autism at 62/10.000, meaning that one out of 160 children is affected by ASD (Vllasaliu et al., 2019). Data regarding the prevalence of ASD are hard to determine. This problem comes from lots of heterogeneity in multiple factors regarding ASD. There are not only various manifestations of the disorder itself, which is also why it is called “Spectrum” but there are also multiple ways to diagnose the disorder and also the system that sets the frame for diagnostic criteria is continuously changing (Vllasaliu et al., 2019). The permanent change in diagnostic criteria is due to constantly changing data, reevaluation and new research findings. Hence, leaving a lot of heterogeneity for the overall picture of ASD, especially when looking at data over a longer period of time. As mentioned before, there are multiple ways the disorder can present itself. Until the introduction of the DSM V, the ranges of the Spectrum were grouped into different subdivisions. However, since the Symptoms of most of the single divisions vary only marginally, it has been decided to group some of them together under the umbrella term “Autism Spectrum Disorder” (Freitag, 2014). By framing it this way, it was tried to clarify that when talking about ASD, one is speaking of a single developmental disorder that only presents itself in different forms and it is only the range of a continuum that we are looking at (Lauritsen, 2013). The term ASD now includes the diagnoses which were formerly known as Autistic Disorder, Asperger’s

Disorder and Pervasive Developmental Disorder – not otherwise specified (PDD-NOS) (Freitag, 2014).

Autistic Disorder

Autistic disorder is a severe developmental disorder, that is usually diagnosed before the age of 3. I n most cases children show strong deficits in social behavior and communication, while repetitive- and stereotypical behavioural patterns are also observed. Additionally, there is often an underdevelopment in speech and intelligence (Interdisziplinäre S3-Leitlinie der DGKJP und der DGPPN sowie der beteiligten Fachgesellschaften, accessed from 27 March 2020).

Asperger’s Disorder

Asperger’s disorder is also determined a severe developmental disorder, which comes along with an impairment in social interactions, Theory of Mind and reduced nonverbal behaviour. Unlike children with Autistic disorder, Children with Asperger’s syndrome hardly ever show an impairment in speech and intelligence. In fact, these kids often score above average at language tests in their age group (Sinzig & Resch, 2012).

PDD – NOS

Children diagnosed with PDD-NOS are usually older than 3 years and often show an impairment in social skills mainly presented by an impairment of either verbal- or nonverbal communication. Also, often observed is the presence of restrictive repetitive behaviour or other stereotypical interests or activities (Wiggins et al., 2019).

Almost continuously there have been three primary complexes of symptoms that make up for the typical diagnostic criteria of ASD: impairment in social interaction, communication and also repetitive- and stereotypical interests and behaviours (Vllasaliu et al., 2019). Besides the primary symptoms, a disruption of so-called Executive Functions has been proclaimed for a long time to be a domain-general characteristic of the autistic cognitive profile (Ozonoff & McEvoy, 1994; Ozonoff, Pennington Bruce, & Rogers Sally, 1991).

Executive Function

EF refers to an umbrella term that comprises multiple interacting cognitive processes in order to engage in goal directed- and other complex and novel behaviour. The concept of EF consists of multiple subdomains, such as: Planning, Set Shifting, Working Memory, Inhibition, Initiation and Monitoring of Action (Hill, 2004). These subdomains will briefly be outlined in the following:

Planning

Planning is a dynamic and complex task, where a sequence of planned actions must be constantly monitored and reevaluated. For adequate planning it is required to observe the current situation, consider what alternatives might come in the future, then implement the new plan and revise it accordingly. Planning is often measured by tasks such as the Tower of London or a Maze Task (Hill, 2004).

Set Shifting

Set Shifting is also often termed as mental flexibility or cognitive flexibility. It describes the ability to change an ongoing thought or action, depending on changes in the environment. A lack of mental flexibility has often been found in ASD and can also be observed in autistic behaviour such as perseveration, repetitiveness and difficulties in adapting to new situations (Hill, 2004).

Working Memory

Working Memory is a cognitive storing process that can temporarily hold information, which is why it is often also called short term memory. It can be divided into a verbal- and spatial component. The concept of Working Memory has been tested in many studies of EF and has often been shown to be impaired in ASD (Wang et al., 2017).

Inhibition

Inhibition is another subdomain of EF that serves the purpose to suppress a prepotent impulse in order to successfully carry out a desired action or thought. The Stroop Interference Test and the Luria handgame are classical measurements for Inhibition (Demetriou, DeMayo, & Guastella, 2019).

Initiation

Initiation is the ability to start a certain task or process. This includes generating thoughts, responses and ideas for possible problem-solving strategies (Cronin & Mandich, 2015). It is usually tested by tasks such as the Verbal Fluency Test or the Hayling Sentence Completion Test (Gibson, Barker, Martin, & Robinson, 2018).

Monitoring of Action

Monitoring of Action is the ability to watch and recognize one’s thoughts, while at the same time adjusting one’s behaviour in order to self-correct those thoughts or actions. Findings regarding an impairment of self-monitoring in ASD have been mixed and must also be distinguished between studies looking at self-monitoring mental processes and those monitoring actions (Hill, 2004).

On the Relevance of Executive Function

Overviewing the large Spectrum of EF that was just presented it is of no surprise that studies regarding the impairment of EF in individuals with ASD present heterogeneous results. On the one hand, it has been found that individuals with ASD show significantly poorer performance in tasks of EF than typically developed control persons (Demetriou et al., 2018). On the other hand, there are multiple studies that did not show any significant impairment of EF in individuals with ASD. There is growing evidence that EF in general have a clear prevalence in ASD (Demetriou et al., 2018). One of the earliest studies regarding EF in ASD was published in 1991 by Pennington and Ozonoff. As one of the first, they were able to shown an EF impairment in not only one but multiple domains of EF, such as planning and problems with set shifting tasks (Jensen, 1999). To date, many studies have followed, that showed general EF impairments in ASD (Demetriou et al., 2019).

Nevertheless, it is still unknown whether a particular subset of EFs is predominantly impaired in autistic individuals (Demetriou et al., 2018). A recent meta-analysis from 2018 has found that across all studies included, there was consistent evidence of a moderate effect size of EF impairment in ASD. When looking at subdomains themselves, the study could only show effect sizes that were defined as small to moderate. These findings again, are in line with the idea that there is no dominating subset of EFs in ASD (Demetriou et al., 2018). Also, it is unclear whether EF bears any relevance for the autism-specific cognitive profile, as lined out in the following.

The heterogeneity of EF findings across studies makes general statements about the relevance of EF impairments for the autistic neurocognitive profile difficult and it is unsatisfactory to attribute this heterogeneity to variability in sampling (Demetriou et al., 2018). The most critical aspect about the role of EF impairments for ASD is the lack of specificity. Importantly, EF impairments can be found across neurodevelopmental disorders (Jensen, 1999), in particular in attention deficit/ hyperactivity disorder (ADHD), which is thought to be genetically overlapping with ASD (Antshel & Russo, 2019) but the two disorders do not share the same phenotype. A recent structural equation modelling study revealed that EF impairments were particularly associated with reported ADHD symptoms in ASD (Lukito et al., 2017).

Furthermore, EF impairments were reported in Tourette's syndrome, obsessive compulsive disorder (Watkins et al., 2005), and in persons with heightened Body Mass Index (Gunstad et al., 2007) all suggesting a contribution of EF to impulse control. Instead EF impairments need to be investigated in the context of autism-specific impairments in order to evaluate their relevance for etiological and treatment considerations.

In contrast to EF impairments, which lack specificity for ASD, there are cognitive particularities that specifically prevail in ASD, namely reduced ToM (Baron-Cohen, 1991) and WCC (Dakin & Frith, 2005), which are further described in the following.

Theory of Mind

ToM or mentalising, relates to the core clinical symptoms of interaction and communication deficits and reflects the ability to attribute mental states to oneself and others to predict or explain a person´s behaviour. An important aspect of ToM is to realize that another person's thoughts might differ from one's own (Bradford, Jentzsch, & Gomez, 2015). Mentalising is a core aspect of human communication and allows a person to understand what someone else thinks or feels even though they are not directly communicating it. Several studies have shown that individuals with ASD show significantly reduced ToM compared to TD individuals (Heavey, Phillips, Baron-Cohen, & Rutter, 2000). Since a lot of people have developed some kind of strategy to compensate for their mentalising impairment, it does not necessarily mean that these people also show a problem in social relationships (Jones Catherine et al., 2017).

Weak Central Coherence

The other primary and highly ASD associated theory is the WCC theory. It refers to difficulties shown by individuals with ASD in perceiving objects, social situations or mental constructs as a whole but instead tending to primarily perceive the details of holistic structures.

Empirically, the WCC was demonstrated by a preference for local over global information processing (Frith, 2003; Muth, Honekopp, & Falter, 2014). However, definite conclusions regarding the performance in global processing are difficult to draw since most experiments have studied mainly local processing (Dakin & Frith, 2005), and some studies showed that people with ASD were capable of global processing when properly instructed (Nuske & Bavin, 2011).

Alternative Theories

It needs to be mentioned that there are now alternative domain-general accounts for functions categorized under the traditional concept of WCC including Enhanced Perceptual Functioning (EPF) (Laurent Mottron, Belleville, & Ménard, 1999) and

Reduced Generalisation (O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001). These theories view WCC as an “effect” of reduced generalisation rather than seeing it as the main explanatory cause (Plaisted, 2001). The theories claim that individuals with ASD are characterised by reduced generalization. Meaning that when looking at a picture, they tend to focus on the single components that the picture is made of, rather than looking at the general construct. In order to test local vs. global processing, tests such as the Embedded Figures Task (EFT) have been established. In tests like the EFT, participants are shown pictures, which are made of single components, e.g. the illustration of a car, which is composed out of circles and triangles. The test person is then asked to count the number of triangles and circles (local processing) and also what the “whole” picture represents (global processing). People with ASD tend to process the local parts faster, than TDs. This reduced generalisation is also the reason why many children and adults with ASD show an advantage over TDs in e.g. EFT and Block Design Tests. For that same reason however, the theory claims, it is that people with ASD have a problem in generalising in social situations (Plaisted, 2001). They show reduced generalisation and are therefore only able to perceive the details when learning a new situation instead of generalising and in consequence then applying the already learned features to a new situation (Burack, Charman, Yirmiya, & Zelazo, 2001).

The Model of Enhanced Perceptual Functioning (EPF) was proposed by Mottron et al. in 2001 as an alternative to the WCC Model (Laurent Mottron & Burack, 2001). It emphasizes the perceptual processes that are involved in perception rather than focusing on cognition or social aspects (L. Mottron, Dawson, Soulieres, Hubert, & Burack, 2006). According to EPF there is a stronger and more pervasive connection of the visual system in people with ASD. Multiple neuroimaging studies have shown increased activity in occipital brain regions in individuals with ASD, in comparison to TDs, implicating a higher involvement of the visual system in ASD and therefore leading to a more detailed processing when looking at pictures (Samson, Mottron, Soulières, & Zeffiro, 2012).

Which Theory is the One?

Yet, none of the mentioned theories so far can be accounted for as the main explanation of ASD. Accordingly, it has been proposed to abandon the idea of a single theory explaining ASD (Happé & Ronald, 2008; Happe, Ronald, & Plomin, 2006). It is therefore of particular interest whether and to what extent the unspecific EF impairments in ASD relate to the highly autism-associated domains, ToM and WCC, in order to understand the relevance of domain-general and presumably fundamental EF for the neurocognitive profile of ASD. Only very few studies so far have researched the interrelationship between these domains. For instance, Rinehart et al. (Rinehart, Bradshaw, Moss, Brereton, & Tonge, 2000) considered that difficulties in global processing might be the result of an inability to switch between the local and global aspects of a stimulus (Laurent Mottron et al., 1999) suggesting a possible relation between WCC and EF, especially with respect to set shifting. Relationships between EF impairments and ToM have likewise been suggested (Lukito et al., 2017) but remain unclear. Especially the matter of set shifting also seems to play an important role in the successful performance for ToM tasks. In order to successfully complete a ToM task, one needs to be able to switch from one's own- to another perspective and therefore set shifting ability is mandatory (Kimhi, 2014) for success. Another connection between EF and ToM is the claim that a certain level of attention is demanded by the individual in order to successfully complete the tasks at hand

(Berenguer, Roselló, Colomer, Baixauli, & Miranda, 2018). However, this theory cannot explain a possible relation specifically between EF and ToM. EF deficits in individuals with ASD have for instance been merely associated with reported ADHD-related symptoms in these individuals, whereas ToM impairments were particularly associated with reported ASD symptoms (Lukito et al., 2017).

Thus, we need to understand whether any EFs, and if so which EFs, might impact the autistic cognitive profile in terms of autism-specific reduced ToM and WCC. This was the aim of the current meta-analysis and cross-study regression.

Method

This is a systematic review and meta-analysis, registered in the Prospero database (registration number: CRD42019139151).

Study Selection

Studies were included if published in English or German between January 1990 (by this year, two of the three cognitive concepts had been established) and December 2018. Eligible studies had to involve participants with a diagnosis of ASD according to DSM-III, DSM-IV, DSM- IVTR, DSM-5, or ICD-10. The studies had to include assessments of at least measures of EF in combination with either ToM or WCC. Also, we only included studies that provided sufficient data to calculate effect sizes and correlations.

Data collection

We searched Medline (via PubMed) and PsycInfo, applying the following generic literature search:

“Autis*” AND “THEORY OF MIND” AND “EXECUTIVE FUNCTION”

“Autis*” AND “THEORY OF MIND” AND “CENTRAL COHERENCE”

“Autis*” AND “CENTRAL COHERENCE” AND “EXECUTIVE FUNCTION”

To cover a broad range of papers the search terms Theory of Mind, Executive Function and Central Coherence were replaced in the process by numerous synonyms and tests respective to their domain as outlined in the following table.

ASD	Executive Function	Theory of Mind	Central Coherence
- Autis* - Asperger - PDD NOS - ASD - Autism - developmental disorder not otherwise specified - developmental disorder	- Response Inhibition - Working Memory - Set Shift - Planning - Inhibition - Impulse Control - Initiation - Generativity - Tower of London - Tower of Hanoi - Flanker Task - Card Sorting - Wisconsin Card Sorting Task - WCST - Numbers Task - Digit Backwards - Short Term Memory	- TOM - ToM - mentalising - mentalizing - social cognition - socialcognition - RMET - reading the mind in the eyes task - false belief task - false believe task - strange stories - mindreading - SallyAnn Task - Sally-Anne Task - Smarties Task	- local/global - Processing - weak central coherence - context - Gestalt - Embedded figures - Detail - Block Design - figure embedding - Navon Figures - Rey ´s figure task

Table 1: Searchwords

For reduction of possible selection bias, screening of titles and abstracts was carried out by two independent evaluators (J.H. & A.B.). The search revealed 71 papers eligible for full-text evaluation. Full-text papers were then also screened by the aforementioned evaluators. We also screened reference lists of all studies eventually included. Regarding the cognitive construct of EF, not all subdomains were included into the analysis, but only those that were tested sufficiently frequently, meaning that subdomains were only selected if they included at least 20 tests. The subdomain that was tested the most was cognitive flexibility with a total of 38 tests, followed by tests of Inhibition (30 tests), planning (22 tests) and working memory (20 tests). Having filtered the initial 71 papers for the inclusion criteria mentioned above, 59 papers remained, 17 of these papers were excluded because they only offered limited data or had other limitations, which made them unsuitable for the purpose of our analysis. Therefore, a total of 42 papers remained for the final analysis. For details of the selection process see the PRSMA flowchart as reported in the following:

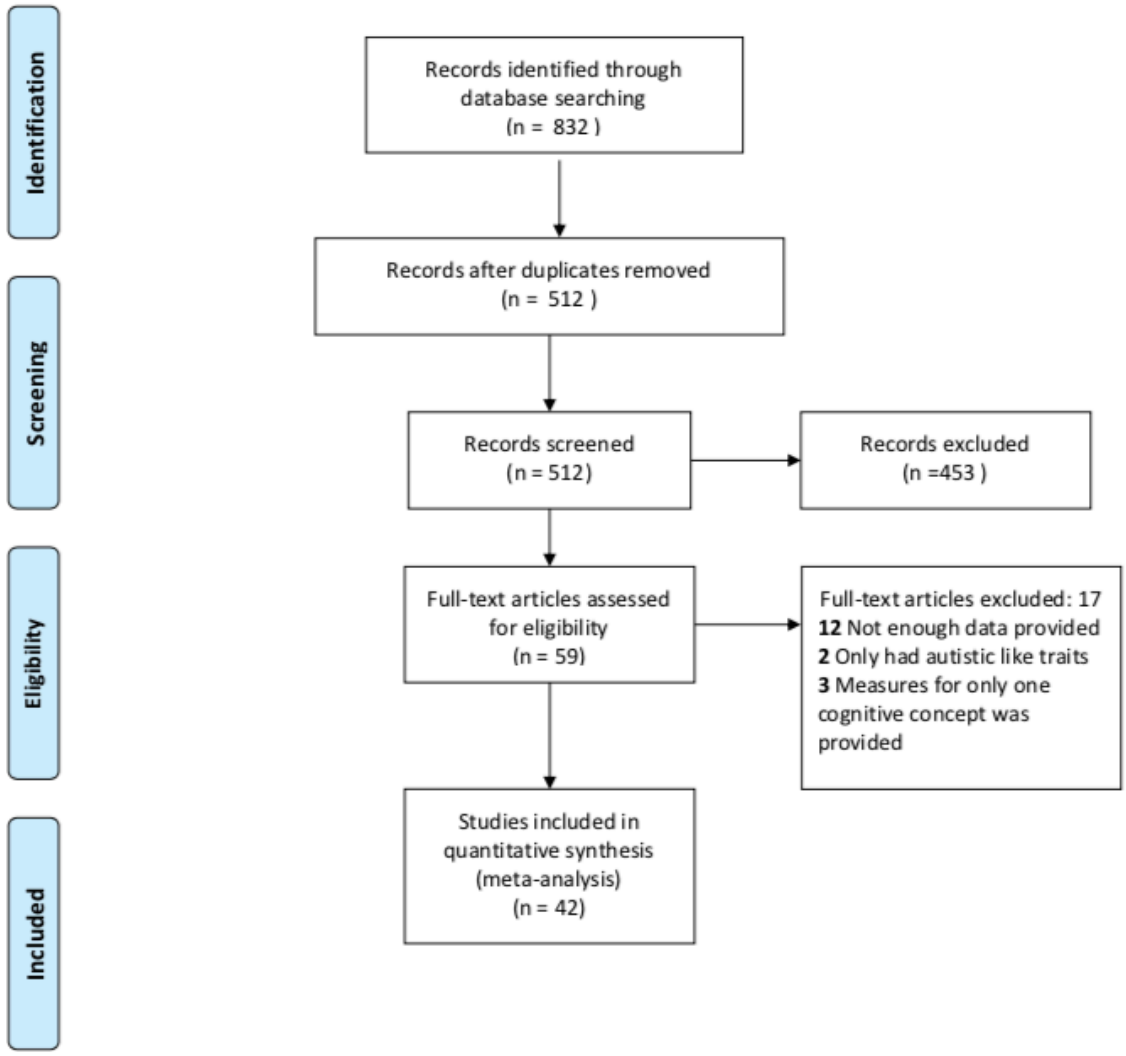


Figure 1: PRISMA Flowchart

Data items and summary measures

For each study, the following additional variables were extracted: title, author, year of publication, demographics of participants (including the specifics of the control groups), exclusion criteria of the respective study, medication taken by participants, comorbidities as well as mean and standard deviation and other measures of dispersion (SE) out of which we calculated standard deviations for our analysis.

Moderator Analysis

We calculated meta-regressions in order to analyse associations of differences between ASD and TD groups with average age of study samples and IQ difference between ASD and TD groups (mixed effects regression, method of moments, CMA 2).

Risk of bias

Two independent raters evaluated each study's quality using the Newcastle Ottawa Quality Assessment Scale for Cohort Studies (NOS) (The Ottawa Hospital Research Institute, accessed 09.01.2020).

Publication bias

For the analysis of publication bias, we employed funnel plots.

Data Analysis

Data Analysis was performed using RevMan 5.3, JMP 15 and CMA Version 2.0. All papers included in the final analysis had investigated EF, either in combination with ToM or WCC among patients with ASD. Out of the 42 identified studies, nine studies did not have a control group and were therefore not included in the calculation of effect sizes, leaving a total of 33 studies for the calculation of effect sizes.

To quantify the magnitude of the different measures of EF, ToM and WCC, we computed effect sizes (Hedges' g) of performance in the ASD group relative to the control group, based on means, standard deviations and sample sizes for each measure. For the meta-analysis, a random effects model was used (DerSimonian & Laird, 1986). Since the cognitive constructs under study are tested by a variety of measures, we used a standardized effect estimate across all tests. Effect benchmarks of Hedges' g can be categorized as the following: *g*: 0,2 – 0,5 = "small", *g*: 0,5 - 0,8 = "medium", *g* > 0,8 = "large". For each analysis, we report the sample sizes of ASD and TD groups, the number of studies included, the effect sizes and their 95% confidence intervals.

Multiple studies used for the meta-analysis showed effect sizes bigger than 1 (with several effect sizes considerably larger than 1, up to 4, see Forest plots), which raised our suspicion on possible reporting errors. All authors of these studies were contacted and asked about possibly mistaken results. Not all authors replied, but of those who did, all of the data had been eventually corrected. However, as a sensitivity analysis, we carried out a meta-analysis without studies reporting an effect size beyond 1.

Studies used different tests and scales in measuring the same psychological construct. For example, the concept of Inhibition, a subdomain of EF, was measured by the BRIEF, the Luria handgame, the Stroop Inhibition Task, a Card Sorting Task and multiple others (Demetriou et al., 2019). To calculate correlations between different psychological concepts among participants with ASD and to estimate the impact of multiple subdomains of EF on ToM or WCC, we standardized all reported results by transforming them to percentages. Where a high test-score indicated bad performance, results were reversed so that, after standardizing, a high percentage always indicated a good result.

To choose regression models, normality was analysed by the Shapiro-Wilk-Test, which showed a normal distribution for almost all measures of Cognition. Therefore, we calculated Pearson's *r* with its 95% confidence intervals between the cognitive Constructs of EF subdomains, ToM and WCC. Since the concept of WCC could only be correlated with very few studies, this variable was omitted from further calculations. A total of eleven studies had to be excluded for the correlation analysis mainly due to missing data, leaving a total of 31 studies that were eligible for this part of the analysis.

We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) (Moher, Liberati, Tetzlaff, Altman, & Group, 2009). An overview of all 42 studies included for the final analysis, with outlined demographics and cognitive Constructs that were analysed, is presented in the following.

				ASD Group			TD Group			Cognitive Construct					
Source	**Publication**	**Diagnostic Criteria**	**NOS Scale**	**N**	**M Age (SD)**	**M IQ (SD)**	**N**	**M Age (SD)**	**M IQ (SD)**	**Inhibition**	**Working Memory**	**Flexibility**	**Planning**	**ToM**	**CC**
Baez	2012	DSM IV	6 (good)	15	35,46 (11,86)	-	15	35,7(11,52)	-	X	X	X			
Beaumont	2008	DSM IV	7 (good)	25	9,52 (0,88)	114 (12,26)		9,52 (0,88)	119,69 (10,49)		X			x	
Berenguer	2018	ADI-R	7 (good)	52	8,59 (1,38)	101,42(12,65)	37	8,54 (1,26)	102,11 (8,91)	X	X	X	X	X	
Berenguer	2018	ADI-R	7 (good)	30	8,39(1,3)	100,37 (12,4)	37	8,54 (1,2)	102,11 (8,9)	X	X	X	X	X	
Beversdorf	1998	ADI-R	6 (good)	10	30,8 (9,3)	109,7 (16,2)	13	30,6 (12)	117,3 (11,2)					X	
Brunsdon	2015	ADOS ADI-R	6 (good)	181	13,49 (0,69)	94,07 (16,91)	160	12,79 (1,1)	102(12,79)	X		X	X	X	X
Cantio	2018	DSM IV	8 (good)	21	10,7 (1,5)	105,48 (15,95)	30	10,96 (1,26)	109,47 (18,58)		X		X	X	X
Durrleman	2015	DSM IV	6 (good)	17	9 (2)	-	17	7,2 (xx)	-	X		X		X	
Edgin	2005	ADI-R	6 (good)	24	11,46 (2,32)	104,4 (20,4)	34	12,4 (2,52)	108,72 (13,04)			X			X

Source	Publication	Diagnostic Criteria	NOS Scale	N	M Age (SD)	M IQ (SD)	N	M Age (SD)	M IQ (SD)	Inhibition	Working Memory	Flexibility	Planning	ToM	CC
Gonzalez	2013	DSM IV	7 (good)	23	33 (9,8)	-	21	38,3 (14,2)	-		X	X		X	
Gonzalez	2014	DSM IV	7 (good)	19	11,89 (2,64)	101,93 (11.96)	19	10,89 (2,3)	100,59 (12,2)	X	X	X		X	
Hanson	2014	DSM IV	5 (fair)	25	5,2 (1,49)	85,71 (21)	25	4,1 (0,93)	109,12 (8)	X	X	X	X	X	
Jones	2017	ICD -10	2 (poor)	100	15,6(0,6)	84,31 (18,03)	-	-	-	X	X	X	x	X	
Joseph	2004	DSM IV	2 (poor)	31	8,9 (2,5)	88 (22,8)	-	-	-	X	X		X		
Kouklari	2018	DSM IV DSM V	6 (good)	45	9,07 (1,42)	97,05 (12,13)	37	9,03 (1,17)	102,11 (14,3)	X	X		X	X	
Kouklari	2018	DSM IV	6 (good)	32	10,34 (1,29)	100,69 (12,85)	32	10 (1,35)	114,81 (9,98)	X	X	X		X	
Kihmhi	2014	DSM IV	7 (good)	29	11,06 (xx)	103,52(17,21)	30	10,97 (xx)	107,6(14,13)				X	X	
Lam	2013	-	4 (fair)	16	8,9 (1,41)	108,44 (12,76)	16	8,42 (2,07)	109,75 (12,58)			X			X
Lam	2012	-	5 (fair)	12	6,11 (8,23)	70,17 (3,51)	12	5,64 (1)	77,91 (3,04)			X			X

Source	Publication	Diagnostic Criteria	NOS Scale	N	M Age (SD)	M IQ (SD)	N	M Age (SD)	M IQ (SD)	Inhibition	Working Memory	Flexibility	Planning	ToM	CC
Low	2009	DSM IV	6 (good)	27	8,26 (2,17)	-	27	6,6(1,31)	-				X	X	X
Lai	2012	-	6 (good)	64	28,15 (6,1)	114,15 (11,15)	64	27,55 (7,7)	113,5 (14,9)	X				X	
Lukito	2017	ADI-R	2 (poor)	100	-	84,3(18)	-	-	-	X	X	X	X	X	
LeSourn	2009	DSM IV	6 (good)	10	16,1 (3,5)	101,8(17,06)	10	15,9(3,6)	98,4(10,9)						
Lind	2014	DSM IV	6 (good)	20	8,67 (1,37)	105,65(16,34)	20	8,31(0,91)	109,05(8,68)						X
Livingston	2018	-	6 (good)	136	13,28 (0,39)	-	136	13,28(0,39)	-	X	x	X	X	X	
Loth	2008	DSM IV	2 (poor)	21	16,8 (6,2)	89,9(23,4)	10	6,3(1,1)	-						X
Lehnhardt	2011	ICD-10	6 (good)	39	31,1 (8,9)	127,9(16,2)	39	31,2(8,1)	133,3(11,6)			X		x	
Mirande	2017	-	7 (good)	52	8,59 (1,38)	101,42 (12,65)	39	8,46(1,27)	102,21 (8,7)	x				x	

Source	Publication	Diagnostic Criteria	NOS Scale	N	M Age (SD)	M IQ (SD)	N	M Age (SD)	M IQ (SD)	Inhibition	Working Memory	Flexibility	Planning	ToM	CC
Montgomery	2013	-	2 (poor)	25	18,2 (1,38)	114(11,1)	-	-	-	X					
Narzisi	2013	DSM IV	7 (good)	22	9,77 (3,65)	99,09(14,23)	40	9,77(3,65)		X	X		X	X	
Ozonoff	1991	DSM III	6 (good)	23	12,05 (3,19)	89,52(15,17)	20	12,39(3,04)	91,3(18,75)	x		X	X		
Pellicano	2007	-	7 (good)	30	5,63 (0,97)	100,03 (10,55)	40	5,47 (0,95)	103,25 (9,92)	X		X	X	X	
Pellicano	2010	DSM IV	4 (poor)	45	5,42 (0,87)	113,27(13,93)	45	5,43(1,05)	115,61(16,42)	X		X	X	X	X
Pellicano	2010	DSM IV	6 (good)	45	5,6 (0,87)	113,27 (13,93)	-	-	-			X	X	X	X
Pellicano	2006	DSM IV	6 (good)	40	5,59 (0,83)	101,15 (11,04)	40	5,47 (0,95)	103,25 (9,91)	X		X	X	X	X
Schuhwerk	2016	ICD-10	7 (good)	14	8 (1,8)	-	21	7,2(1,4)	-					X	
Stichter	2012	ADI-R ADOS	4 (poor)	20	8,77 (1,3)	99,3(15,18)	-	-	-	X	X	X	X	X	
VanMarcke	2016	DSM IV	5 (fair)	24	20,63(0,38)	107,63(8,7)	24	20,83(0,41)	108,9(6,05)	X	X	X	X	X	

Source	Publication	Diagnostic Criteria	NOS Scale	N	M Age (SD)	M IQ (SD)	N	M Age (SD)	M IQ (SD)	Inhibition	Working Memory	Flexibility	Planning	ToM	CC
Vanegas	2015	-	7 (good)	24	9,7 (1,35)	100,72 (14,32)	25	8,86(1,09)	110,12 (14,59)	X	X	X	X		X
Williams	2013	-	5 (fair)	21	10,6 (2,01)	110,19(16,35)	21	10,59(1,31)	107,48(13,23)			X		X	
Yang	2009	DSM IV	6 (good)	20	15,5 (8,1)	96,68 (24,63)	30	8(3,1)	118,23 (12,06)	X	X	X		X	
Zelazo	2002	DSM III - R	2 (poor)	22	13,88 (4,75)	42,59 (13,32)	-	-	-	X		X		X	

Table 2: Included Studies

Note: This Table presents Demographics of the samples observed and the cognitive Constructs that were measured for each study.

Abbreviations stand for: ASD= Autism Spectrum Disorder, TD = Typically Developing, NOS = Newcastle Ottawa Scale, ToM = Theory of Mind, CC = Central Coherence

Results

Retrieved Studies

Data came from a total of 42 studies used for the final analysis. The literature search yielded data from 1546 participants with ASD (grand mean age = 13.36, *SD* = 8.37, mean age range: 4.95 – 35.46, grand median age = 10.05 years), that were compared to 1206 TD individuals (grand mean age = 13.17, *SD* = 11.85, mean age range: 4.1 – 38.3 years, grand median age = 8.94 years). Sample sizes ranged from a minimum of ten participants to a maximum of 181.

The grand mean IQ of the ASD group was *M* = 101.82, *SD* = 10.76 and that of the TD group was *M* = 104.03, *SD* = 21.63. There was no significant effect for IQ between the two groups $t(33) = 0.739$, $p = .536$.

	N	Age (M,SD)	IQ (M, SD)
ASD Group	1546	13,36 (8,37)	101,82 (10,76)
TD Group	1206	13,17 (11,85)	104,03 (21,63)

Table 3: Demographics

Meta-Analysis: Cognitive Constructs

The different subgroups of EF that were analysed showed small to moderate effect sizes: for Inhibition (EF1) (*k* = 15, *g* = - 0.78, 95 % CI [-1.03, -0.53], I^2 = 72%), with a total of *n* = 575 participants with ASD and *n* = 578 TD participants; Working Memory (EF2) (*k* = 11, *g* = - 0.79, 95 % CI [-1.33,-0.25], I^2 = 89%, ASD *n* = 286, TD *n* = 303); Flexibility (EF3) (*k* = 19, *g* = - 0.47, 95 % CI [-0,73,-0.21], I^2 = 79%) with *n* = 647 participants with ASD and *n* = 657 TD participants; Planning (EF4) (*k* = 13, *g* = - 0.81, 95 % CI [-1.16,-0.46], I^2 = 85%, ASD *n* = 557, TD *n* = 549).

Participants with ASD (*n* = 873) performed poorer compared to TD participants (*n* = 870) in ToM tasks, with a large effect size (*k* = 24, *g* = - 0.81, 95 % CI [-1.10, -0.52], I^2 = 87%).

With regard to CC, participants with ASD (*n* = 403) showed lower test scores relative to TD participants (*n* = 413), with a large effect size (*k* = 9, *g* = -0.80, 95 % CI [-1.43, -0.17], I^2 = 93%).

Since some studies that were included in the meta-analysis showed effect sizes larger than 1, a complementary analysis was performed with all studies excluded that showed an effect size greater than one.

The different subgroups of EF that were analysed showed small to moderate effect sizes: for the matter of Inhibition (*k* = 10, *g* = - 0.53, 95 % CI [-0.76, -0.29], I^2 = 56%), with a total of *n* = 422 participants with ASD and *n* = 420 TD participants; Working Memory (*k* = 8, *g* = - 0.34, 95 % CI [-0.68, -0.01], I^2 = 64%, ASD *n* = 188, TD *n* = 197); Flexibility (*k* = 15, *g* = - 0.44, 95 % CI [.0,59,-0.28], I^2 = 27%) with *n* = 510 participants with ASD and *n* = 527 TD participants Planning (*k* = 9, *g* = - 0.44, 95 % CI [-0.66, 0.22], I^2 = 53%, ASD *n* = 421, TD *n* = 436).

Participants with ASD performed poorer (*n* = 682) compared to TD participants (*n* = 696) in ToM tasks, with a moderate effect size (*k* = 19, *g* = - 0.51, 95 % CI [- 0.71, -0.31], I^2 = 66%).

With regard to CC participants with ASD (*n* = 326, they showed lower test scores relative to TD participants (*n* = 342), with a small effect size (*k* = 7, *g* = - 0.31, 95 % CI [-0.64, 0.02], I^2 = 71%). For details of the outlined results see the following Forest Plots.

Forest plot:inhibition

Study or Subgroup	ASD Mean	ASD SD	ASD Total	TD Mean	TD SD	TD Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.1.1 EF1								
Baez 2012	9.07	7.36	15	6	3.89	15	1.5%	0.51 [−0.22, 1.24]
Berenguer 2018	87.6	14.05	52	104.22	6.49	37	1.8%	−1.43 [−1.90, −0.95]
Berenguer 2018_2	91.8	14.11	30	102.35	6.49	37	1.8%	−0.98 [−1.50, −0.47]
Brunsdon 2015	8.44	2.72	181	9.78	0.6	160	2.1%	−0.66 [−0.88, −0.44]
Durrleman 2015	89.2	31.2	17	80.4	16.9	17	1.6%	0.34 [−0.34, 1.02]
Gonzalez 2014	28.81	9.91	19	32.38	8.72	19	1.6%	−0.37 [−1.02, 0.27]
Hanson 2014	10.13	7.16	25	15.63	5.36	25	1.7%	−0.86 [−1.44, −0.27]
Kouklari 2018	9.48	3.05	32	12.22	1.41	32	1.8%	−1.14 [−1.67, −0.61]
Kouklari 2018_2	272.23	16.04	45	283.14	20.46	37	1.9%	−0.60 [−1.04, −0.15]
Narzisi 2013	1.82	10.88	22	9.64	2.34	44	1.7%	−1.19 [−1.74, −0.63]
Ozonoff 1991	19.78	9.85	23	37.45	8.65	20	1.5%	−1.86 [−2.59, −1.13]
Pellicano 2006	7.1	1.64	40	8.15	1.46	40	1.9%	−0.67 [−1.12, −0.22]
Pellicano 2007	7.27	1.74	30	8.15	1.46	40	1.8%	−0.55 [−1.03, −0.07]
Vanegas 2015	86.08	11.44	24	100.6	10.79	25	1.6%	−1.29 [−1.91, −0.67]
Yang 2009	4.71	3.06	20	7.12	3.08	30	1.7%	−0.77 [−1.36, −0.18]
Subtotal (95% CI)			**575**			**578**	**26.0%**	**−0.78 [−1.03, −0.53]**

Heterogeneity: Tau² = 0.16; Chi² = 49.69, df = 14 (P < 0.00001); I² = 72%
Test for overall effect: Z = 6.19 (P < 0.00001)

Forest plot:working memory

Study or Subgroup	ASD Mean	ASD SD	ASD Total	TD Mean	TD SD	TD Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.1.2 EF2								
Baez 2012	23.92	11.6	15	24.28	11.11	15	1.5%	−0.03 [−0.75, 0.68]
Beaumont 2006	15.05	3.5	20	17.3	1.81	20	1.6%	−0.79 [−1.44, −0.15]
Berenguer 2018	84.27	10.37	52	104.22	6.6	37	1.8%	−2.20 [−2.73, −1.66]
Cantio 2018	−0.0262	0.94	21	0	1	30	1.7%	−0.03 [−0.58, 0.53]
Gonzalez 2013	5.61	1.31	23	5.4	1.47	21	1.7%	0.15 [−0.44, 0.74]
Gonzalez 2014	13.21	2.95	19	14.94	3.71	19	1.6%	−0.51 [−1.15, 0.14]
Hanson 2014	1.8	1.96	25	1.42	0.12	25	1.7%	0.27 [−0.29, 0.83]
Kouklari 2018	7.18	3.03	45	9.71	2.39	37	0.0%	−0.91 [−1.37, −0.45]
Kouklari 2018_2	7.18	3.03	45	9.71	2.39	37	1.9%	−0.91 [−1.37, −0.45]
Narzisi 2013	1.3	4.48	22	9.57	2.3	44	1.6%	−2.57 [−3.25, −1.88]
Vanegas 2015	86.08	11.44	24	100.6	10.79	25	1.6%	−1.29 [−1.91, −0.67]
Yang 2009	9.21	3.35	20	12.21	3.94	30	1.7%	−0.79 [−1.38, −0.21]
Subtotal (95% CI)			**286**			**303**	**18.4%**	**−0.79 [−1.33, −0.25]**

Heterogeneity: Tau² = 0.73; Chi² = 91.05, df = 10 (P < 0.00001); I² = 89%
Test for overall effect: Z = 2.88 (P = 0.004)

Forest plot: flexibility

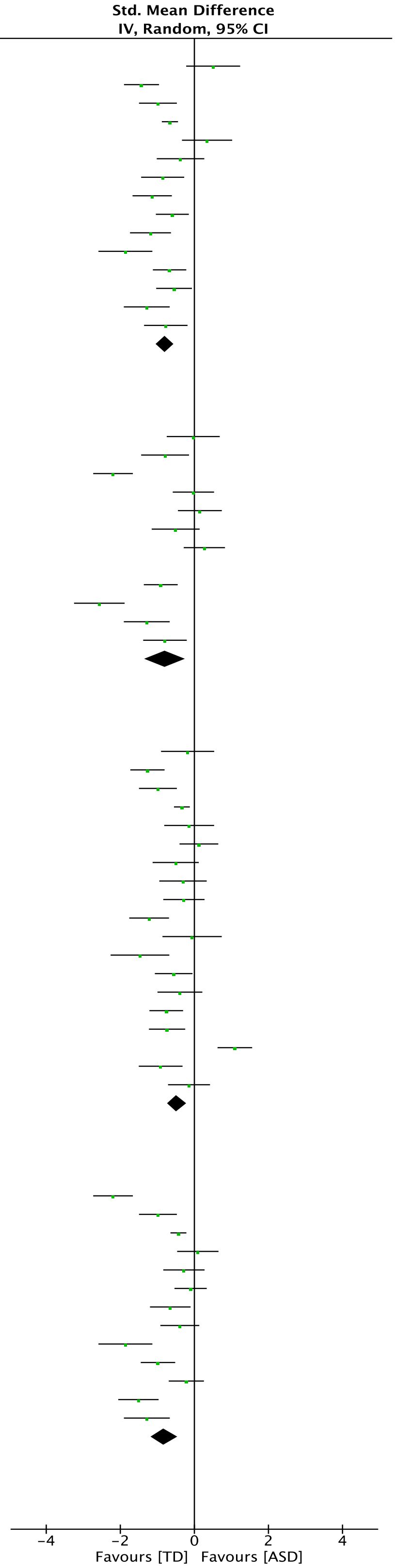
Study or Subgroup	ASD Mean	ASD SD	ASD Total	TD Mean	TD SD	TD Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.1.3 EF3								
Baez 2012	602.15	118.08	15	632.04	191.65	15	1.5%	−0.18 [−0.90, 0.53]
Berenguer 2018	87.6	14.05	52	102.35	6.49	37	1.8%	−1.27 [−1.73, −0.80]
Berenguer 2018_2	91.8	14.11	30	102.35	6.49	37	1.8%	−0.98 [−1.50, −0.47]
Brunsdon 2015	2.32	2.69	180	3.08	1.62	161	2.1%	−0.34 [−0.55, −0.12]
Durrleman 2015	78.4	41.2	17	82.8	13	17	1.6%	−0.14 [−0.81, 0.53]
Edgin 2005	8.21	0.93	24	8.09	1	34	1.8%	0.12 [−0.40, 0.64]
Gonzalez 2013	5.17	1.67	20	5.8	0.52	21	1.6%	−0.50 [−1.13, 0.12]
Gonzalez 2014	186.78	53.59	19	200.11	26.99	19	1.6%	−0.31 [−0.95, 0.33]
Hanson 2014	4.48	2.45	25	5.13	2.05	25	1.7%	−0.28 [−0.84, 0.27]
Kouklari 2018	8.94	2.64	32	12.25	2.71	32	1.8%	−1.22 [−1.76, −0.69]
Lam 2012	51.08	11.59	12	51.67	6.1	12	1.4%	−0.06 [−0.86, 0.74]
Lam 2013	16.5	18.98	16	39.81	10.85	16	1.4%	−1.47 [−2.26, −0.68]
Li 2014	21.38	9.12	31	26.26	8.09	31	1.8%	−0.56 [−1.07, −0.05]
Ozonoff 1991	2.3	31.5	23	13.7	24.9	20	1.7%	−0.39 [−1.00, 0.21]
Pellicano 2006	14.95	9.79	40	21.78	7.92	40	1.9%	−0.76 [−1.21, −0.31]
Pellicano 2007	16.3	9.64	30	22.78	7.92	40	1.8%	−0.74 [−1.23, −0.25]
Pellicano 2010_2	0.32	0.07	37	0.23	0.09	45	1.8%	1.09 [0.62, 1.56]
Vanegas 2015	86.1	15.32	24	100.6	15.99	25	1.7%	−0.91 [−1.50, −0.32]
Yang 2009	0.63	0.13	20	0.65	0.14	30	1.7%	−0.14 [−0.71, 0.42]
Subtotal (95% CI)			**647**			**657**	**32.6%**	**−0.47 [−0.73, −0.21]**

Heterogeneity: Tau² = 0.26; Chi² = 87.55, df = 18 (P < 0.00001); I² = 79%
Test for overall effect: Z = 3.53 (P = 0.0004)

Forst plot: planning

Study or Subgroup	ASD Mean	ASD SD	ASD Total	TD Mean	TD SD	TD Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.1.4 EF4								
Berenguer 2018	84.27	10.37	52	104.22	6.6	37	1.8%	−2.20 [−2.73, −1.66]
Berenguer 2018_2	91.8	14.11	30	102.35	6.49	37	1.8%	−0.98 [−1.50, −0.47]
Brunsdon 2015	2.78	1.01	181	3.18	0.82	160	2.1%	−0.43 [−0.65, −0.22]
Cantio 2018	0.083	0.68	21	0	1	30	1.7%	0.09 [−0.47, 0.65]
Hanson 2014	2.21	2.08	25	2.79	1.96	25	1.7%	−0.28 [−0.84, 0.27]
Kouklari 2018	7.26	2.04	45	7.45	1.58	37	1.9%	−0.10 [−0.54, 0.33]
Low 2009	13.11	6.4	27	16.87	4.89	27	1.7%	−0.65 [−1.20, −0.10]
Narzisi 2013	5.18	18.84	22	9.68	2.35	40	1.8%	−0.39 [−0.92, 0.13]
Ozonoff 1991	19.78	9.85	23	37.45	8.65	20	1.5%	−1.86 [−2.59, −1.13]
Pellicano 2006	6.32	2.62	40	9.3	3.34	40	1.8%	−0.98 [−1.45, −0.52]
Pellicano 2007	14.5	5.04	30	15.38	3	40	1.8%	−0.22 [−0.69, 0.26]
Pellicano 2010_2	6.33	2.8	37	10.52	2.67	31	1.7%	−1.51 [−2.06, −0.97]
Vanegas 2015	86.1	11.44	24	100.6	10.79	25	1.6%	−1.28 [−1.90, −0.66]
Subtotal (95% CI)			**557**			**549**	**23.1%**	**−0.81 [−1.16, −0.46]**

Heterogeneity: Tau² = 0.34; Chi² = 82.55, df = 12 (P < 0.00001); I² = 85%
Test for overall effect: Z = 4.58 (P < 0.00001)



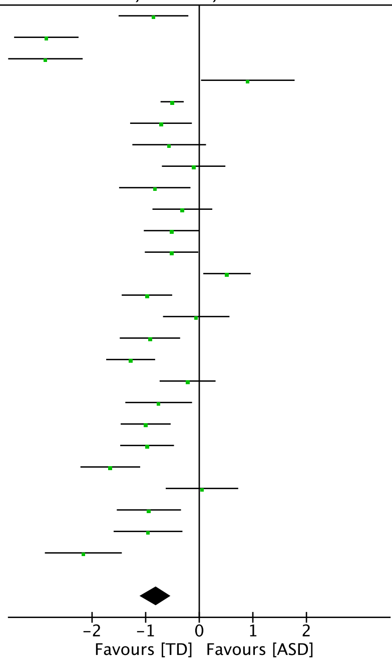
Graph 2: Forest Plot – Executive Function: Subgroup Analysis of EF domains. Results show medium effect size measures for all EF subtypes observed.

Note: graphical explanations: horizontal lines present 95% Confidence Interval of the effect sizes for each study; green dot: hedges'g; diamond shape: overall effect size.

Forest plot: Theory of Mind

Study or Subgroup	ASD Mean	ASD SD	ASD Total	TD Mean	TD SD	TD Total	Weight	Std. Mean Difference IV, Random, 95% CI
Beaumont 2006	4.65	1.6	20	5.75	0.79	20	3.7%	−0.85 [−1.50, −0.20]
Berenguer 2018	11.51	2.88	52	18.38	1.42	37	3.8%	−2.85 [−3.45, −2.25]
Berenguer 2018_2	12.04	2.86	30	18.38	1.42	37	3.6%	−2.87 [−3.57, −2.18]
Beversdorf 1998	−4.2	1.3	10	−5	0.01	13	3.2%	0.91 [0.03, 1.78]
Brunsdon 2015	9.22	1.34	181	9.77	0.69	160	4.5%	−0.51 [−0.72, −0.29]
Cantio 2018	−0.95	1.66	21	0	1	30	3.9%	−0.71 [−1.29, −0.14]
Durrleman 2015	69.2	33.2	17	84.4	17.2	17	3.6%	−0.56 [−1.25, 0.13]
Gonzalez 2013	13.7	2.99	23	13.95	1.28	21	3.8%	−0.11 [−0.70, 0.49]
Gonzalez 2014	15.94	5.48	19	19.87	3.6	19	3.7%	−0.83 [−1.50, −0.16]
Hanson 2014	0.42	0.5	25	0.58	0.5	25	3.9%	−0.31 [−0.87, 0.24]
Kihmhi 2014	0.41	0.73	29	0.83	0.87	30	4.0%	−0.52 [−1.03, 0.00]
Kouklari 2018	18.32	4.05	32	20.16	2.88	32	4.0%	−0.52 [−1.02, −0.02]
Kouklari 2018_2	3.93	2.87	45	2.76	1.04	37	4.1%	0.52 [0.07, 0.96]
Lehnhardt 2011	15.2	5.1	39	19.1	2.3	39	4.1%	−0.98 [−1.45, −0.51]
Lind 2014	3	0.79	20	3.05	0.94	20	3.8%	−0.06 [−0.68, 0.56]
Low 2009	1.63	1.28	27	2.59	0.69	27	3.9%	−0.92 [−1.48, −0.36]
Mirande 2017	17.96	4.15	52	22.5	2.42	39	4.1%	−1.28 [−1.74, −0.82]
Narzisi 2013	9.83	3.81	22	10.57	3.09	40	4.0%	−0.22 [−0.74, 0.30]
Ozonoff 1991	0.65	0.49	23	0.95	0.22	20	3.8%	−0.76 [−1.38, −0.13]
Pellicano 2006	4.18	3.64	40	8.02	3.96	40	4.1%	−1.00 [−1.47, −0.53]
Pellicano 2007	2.53	2.27	30	4.35	1.46	40	4.0%	−0.97 [−1.47, −0.47]
Pellicano 2010_2	1.92	2.13	37	4.84	1.1	31	3.9%	−1.66 [−2.22, −1.10]
Schuhwerk 2016	0.23	0.33	14	0.21	0.42	21	3.6%	0.05 [−0.63, 0.73]
VanMarcke 2016	30.04	9.43	24	39.21	9.76	24	3.8%	−0.94 [−1.54, −0.34]
Williams 2013	0.55	0.83	21	1.81	1.63	21	3.7%	−0.96 [−1.60, −0.31]
Yang 2009	1.32	1.38	20	3.77	0.9	30	3.6%	−2.16 [−2.88, −1.45]
Total (95% CI)			**873**			**870**	**100.0%**	**−0.81 [−1.10, −0.52]**

Heterogeneity: $Tau^2 = 0.47$; $Chi^2 = 190.29$, df = 25 ($P < 0.00001$); $I^2 = 87\%$
Test for overall effect: Z = 5.52 ($P < 0.00001$)



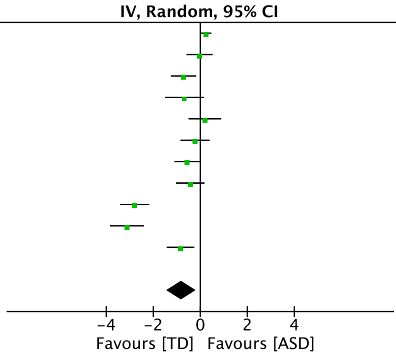
Graph 3: Forest plot - Theory of Mind **-**. Results show large effect size measures for Theory of Mind.

Note: graphical explanations: horizontal lines present 95% Confidence Interval of the Effect Sizes for each study; green dot: hedges‘g; diamonds shape: overall effect size.

Forest plot: Central Coherence

Study or Subgroup	ASD Mean	ASD SD	ASD Total	TD Mean	TD SD	TD Total	Weight	Std. Mean Difference IV, Random, 95% CI
Brunsdon 2015	20.4	10.7	159	17.9	9.32	158	9.8%	0.25 [0.03, 0.47]
Cantio 2018	0.98	0.86	21	1	0.2	30	9.2%	−0.03 [−0.59, 0.52]
Edgin 2005	13.89	5.94	24	20.64	11.05	34	9.3%	−0.72 [−1.26, −0.18]
Lam 2012	109.95	59.59	12	157.88	76.38	12	8.5%	−0.68 [−1.50, 0.15]
Lam 2013	208.44	195.13	16	176.44	122.34	16	8.9%	0.19 [−0.50, 0.89]
Lind 2014	24.22	16.22	20	27.55	12.34	20	9.1%	−0.23 [−0.85, 0.40]
Low 2009	10.6	4.16	27	13.19	4.9	27	9.2%	−0.56 [−1.11, −0.02]
Ozonoff 1991	16.35	5.77	23	18.75	5.18	20	9.1%	−0.43 [−1.03, 0.18]
Pellicano 2006	5.49	3.21	40	13.82	2.67	40	9.0%	−2.79 [−3.42, −2.17]
Pellicano 2010_2	5.46	2.88	37	14.11	2.56	31	8.8%	−3.12 [−3.84, −2.40]
Vanegas 2015	0.5	0.17	24	0.65	0.18	25	9.1%	−0.84 [−1.43, −0.26]
Total (95% CI)			**403**			**413**	**100.0%**	**−0.80 [−1.43, −0.17]**

Heterogeneity: $Tau^2 = 1.03$; $Chi^2 = 153.24$, df = 10 ($P < 0.00001$); $I^2 = 93\%$
Test for overall effect: Z = 2.50 (P = 0.01)

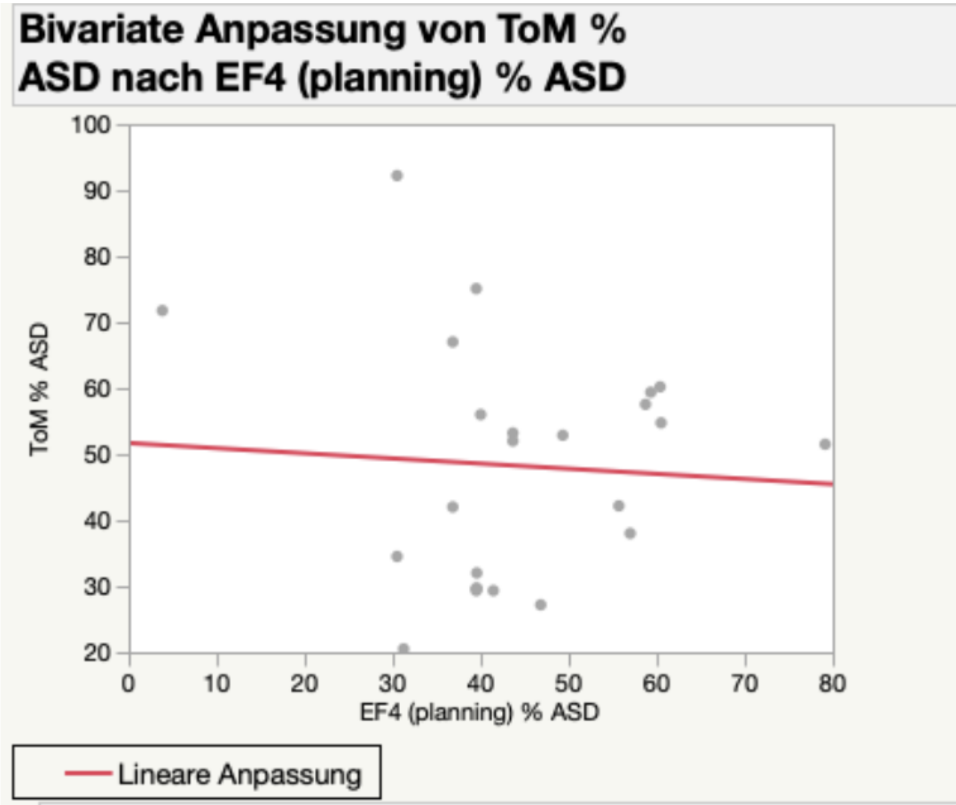


Graph 4: Forest Plot - Central Coherence **-** Results show large Effect Size for Central Coherence.

Note: graphical explanations: horizontal lines present 95% Confidence Interval of the Effect Sizes for each study; green dot: hedges‘g; diamonds shape: overall effect size.

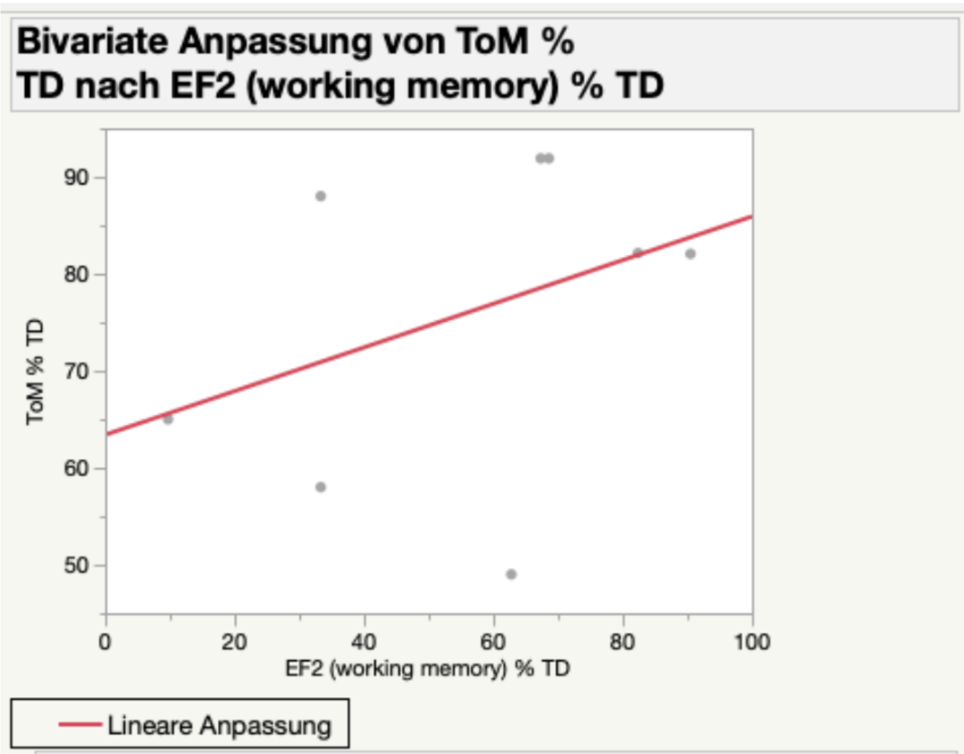
Regression

In general, the correlations between the EF subdomains and ToM can be categorized as small for the ASD and the TD group. Correlations ranged from r (6) = .143, p = .353 for working memory in the TD group to r (22) = .0040, p = .7667 between planning and ToM in the ASD. The scatter plots including the largest and smallest correlations are presented in the following.



Graph 3: Regression Analysis – smallest correlation observed: Planning/Theory of Mind

Note: Relationship between Planning and Theory of Mind in individuals with Autism Spctrum Disorder, Pearsons r = .004



Graph 4: Regression Analysis – largest correlation observed: Working Memory/Theory of Mind

Note: Relationship between Working Memory and Theory of Mind in typically developing individuals, Pearsons r = .143

Moderator Analysis

In meta-regressions, we found no association between effect sizes and IQ difference between ASD and TD groups. When looking at WCC, a significant effect for Age was observed (slope = .22, p = .031, df = 10). The difference in CC measures between the ASD and TD group, became weaker with increasing age of participants.

Risk of Bias

For assessing risk of bias of individual studies the NOS was evaluated, it showed an average overall score of 5.21 points. The NOS scale ranges from 0 to 9 points. Regarding analysis of studies that were included, a minimum of 2 points and a maximum of 8 points were observed. Based on the results of this analysis the quality of studies that were analysed can be placed on a scale between fair and good quality. Having filtered all studies by quality, a further meta-analysis was performed that only included studies that were rated as “good” (at least 6 points).

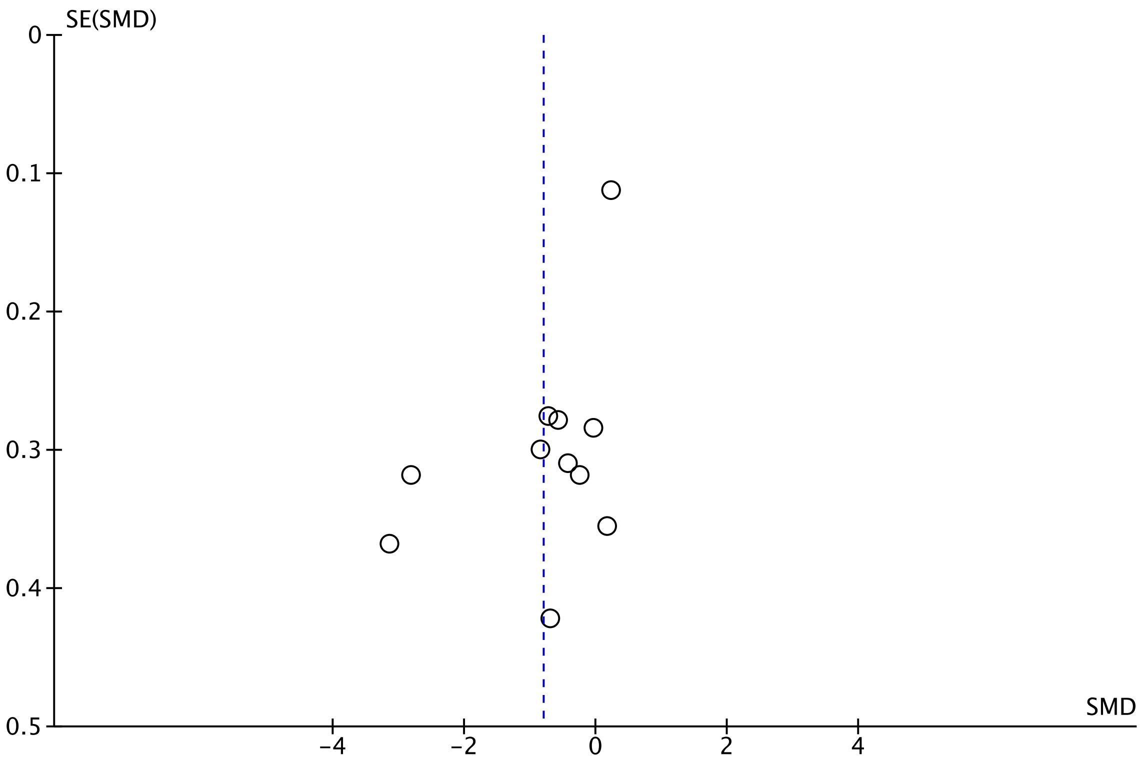
The different subgroups of EF that were analysed showed large to moderate effect sizes: for the matter of Inhibition (k = 14, g = - 0.77, 95% CI [-1.04, -0.51], I^2 = 74%), with a total of n = 550 participants with ASD and n = 553 TD participants; Working Memory (k = 11, g = - 0.9, 95% CI [-1.38, -0.42], I^2 = 87%, ASD n = 306, TD n = 315); Flexibility (k = 16, g = - 0.55, 95% CI [-0.75, -0.35], I^2 = 59%) with n = 582 participants with ASD and n = 584 TD participants Planning (k = 11, g = - 0.79, 95% CI [-1.17, -0.42], I^2 = 86%, ASD n = 495, TD n = 493).

Participants with ASD performed poorer (n = 766) compared to TD participants (n = 769) in ToM tasks, with a moderate effect size (k = 20, g = - 0.78, 95% CI [-1.10, -0.46], I^2 = 88%).

With regard to CC, participants with ASD (*n* = 338) showed lower test scores relative to TD participants (*n* = 354), with a moderate effect size (*k* = 6, *g* = - 0.65, 95% CI [-1.29, -0.02], I^2 = 92%).

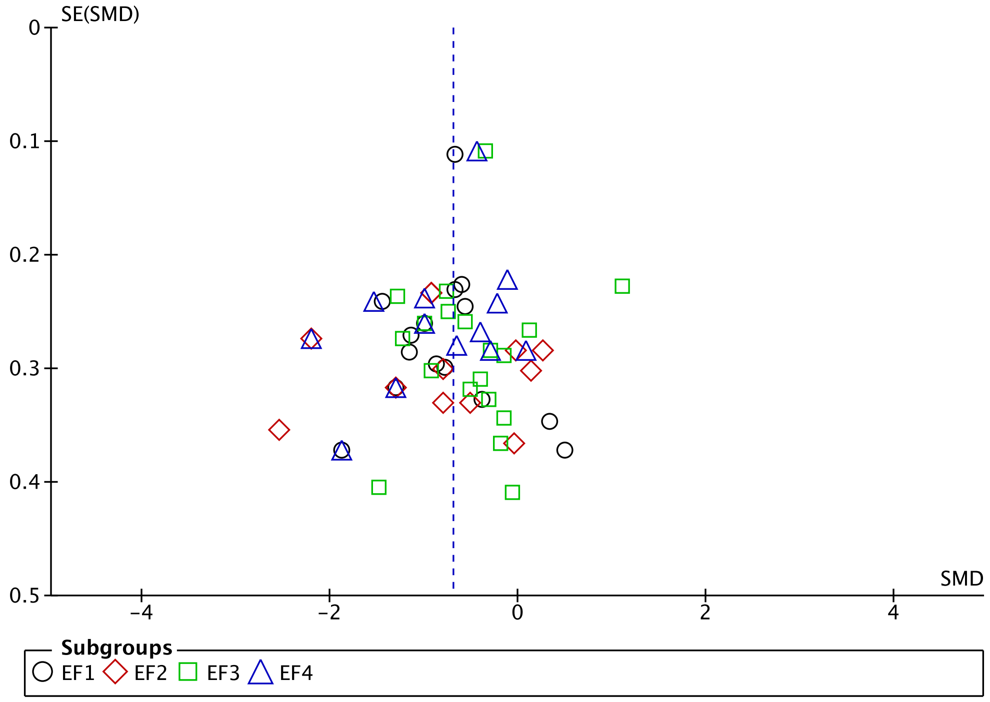
Publication bias

Funnel plots were generated for each cognitive Construct that was analysed. All constructs included data of at least 10 studies. Funnel plots did not indicate a publication bias as demonstrated in the following figures.



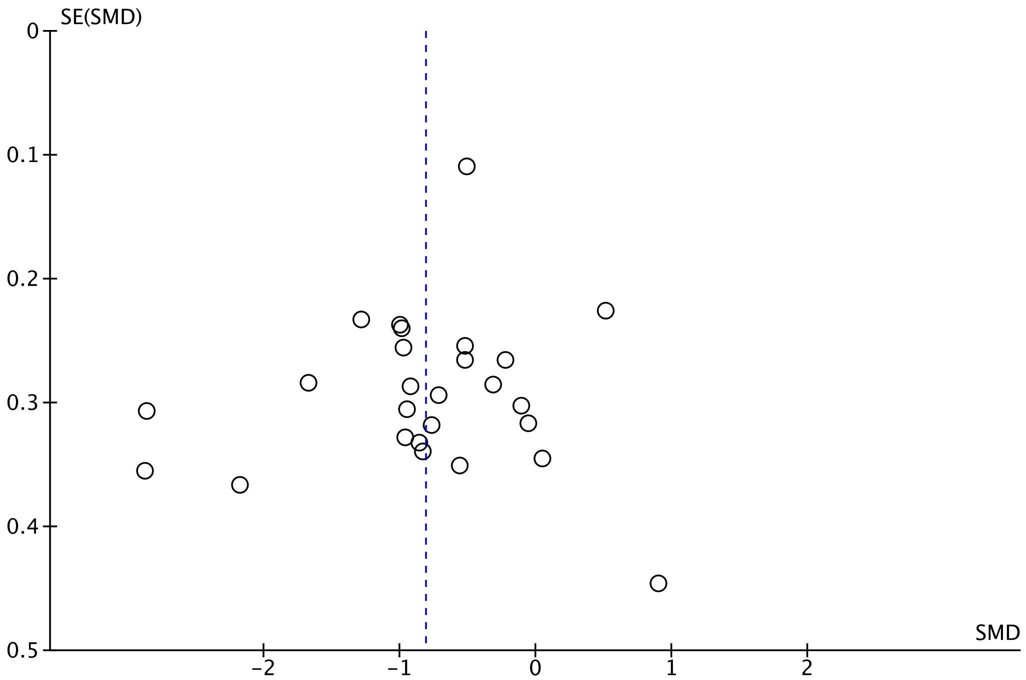
Graph 6: Funnel plot for 11 studies comparing Central Coherence performance between ASD and TD.

Note: SMD: Standard Mean Difference (effect size); SE: Standard Error. Positive effect sizes indicate superior performance in ASD. The solid vertical line indicates the estimate for the population effect size.



Graph 7: Funnel plot of studies comparing Executive Function performance between ASD and TD.

Note: SMD: Standard Mean Difference (Effect Size); SE: Standard Error; EF1: Inhibition: EF2: Working Memory; EF3: Flexibility; EF4: Planning. Positive effect sizes indicate superior performance in ASD. The solid vertical line indicates the estimate for the population effect size.



Graph 8: Funnel Plot - Theory of Mind Funnel plot for 26 studies comparing Theory of Mind performance between ASD and TD.

Note: SMD: Standard Mean Difference (effect size); SE: Standard Error. Positive effect sizes indicate superior performance in ASD. The solid vertical line indicates the estimate for the population effect size.

Discussion

The aim of this meta-analysis was to investigate the differential influence of domain-general, unspecific EF impairments and its subdomains on autism-associated ToM and WCC in persons with ASD.

In comparison to TD controls, participants with ASD showed significant impairment in all three cognitive domains under study, EF, ToM, and WCC. The largest group differences were found in the autism-specific domains ToM and WCC. With respect to EF, we found deficits in persons with ASD with moderate effect sizes for all studied subdomains. The largest effect size was found for Planning, followed by Working Memory, Inhibition, and Flexibility. These results are in accordance with previous findings of EF in ASD (Demetriou et al., 2018; Lai et al., 2017).

Importantly, the regression analyses showed no significant association between any of the EF subdomains and ToM, neither for the ASD nor the TD group. To our knowledge, so far, no previous study has looked at the relationship of these two cognitive domains employing meta-analytical tools before. Since previous studies had already speculated that the impairment in ToM, that is regularly observed in ASD, might be understood as a consequence of EF dysfunctions (Hill, 2004; J. Russell, Jarrold, & Henry, 1996) it shows a clear gap in research. Thus, the current study is supposed to clarify and specify the role of EF for the autistic-cognitive profile.

The lack of a significant association between EF and ToM, as shown by our analyses, rather points at independent dysfunctions of the two domains. The idea that ASD cannot be explained by one overall impairment but should rather be seen as a fractionation of symptoms and an accumulation of multiple independent dysfunctions was introduced by Happe et al. in 2006 (Happe et al., 2006). They claimed that based on their studies, participants did not always show an equal amount of impairment in all three social- and cognitive domains. Additionally, a population based study with data from 3000 twin-pairs only found modest to low correlations between the autistic traits in the three areas (Happe et al., 2006). These findings further support the idea that impairments observed in ASD should be seen as independent dysfunctions. While the cognitive Concepts for EF and WCC were not continuously observed in people with ASD, the Concept of ToM continuously was (Lam, 2013). Hence, it can be stated that ToM can be regarded as clearly autism-associated (Lam, 2013; Lukito et al., 2017).

Limitations

Due to limitation in the number of studies, a correlation analysis for the EF subdomains and WCC was not possible. The association between EF and WCC will therefore need to be re-evaluated in future studies, once sufficient evidence has accumulated. As other perceptual processing theories such as EPF and reduced generalization are also becoming more and more prominent (L. Mottron et al., 2006) it might become difficult to gather that same general overview for WCC and EF as for the associations between EF and ToM.

As a common limitation in ASD research, the included samples were very heterogeneous in multiple aspects, such as sample size and inclusion criteria. For instance, some studies allowed for comorbidities or measured the severity of symptoms whereas others did not. Therefore, all participants that were finally included showed highly different grades of impairment, limiting comparability, but at the same time reflecting the nature of the spectrum. Likewise, studies were heterogeneous in terms of paradigms and methodology. For instance, among the four subdomains of EF that we included, there were at least 16 different tests reported. Moreover, the tests have sometimes been adapted to a special sample, e.g. a version for children, or the tests had been shortened due to limited attention of participants. This clinical- and methodological heterogeneity is reflective of the field as a whole and while we counteracted it by applying random effects models it still calls for cautious interpretation.

Some included studies reported unusually high effect sizes. However, with exception of CC, our findings remained largely unchanged after excluding studies with particularly high effect sizes.

Moderator Analysis - IQ

Moderator Analysis looked at possible effects of Age and IQ on the results of our findings. Regarding IQ no moderator effect was found for our data. This finding seems counterintuitive at first, since one would think, that IQ would influence the findings observed. However, it could be that the findings of our moderator analysis are due to selection biases made by the studies that were used. The first point where a selection bias could have occurred is that, data did not come from a randomized sample. The other issue is, that most studies had determined inclusion criteria, that only allowed for participants with an IQ > 70 to take part in their study. Furthermore, not all studies that were included reported sufficient information regarding IQ of subjects. This occurs to be a common problem in ASD research and is especially prone to bias, when constructing a meta-analysis. A recent meta-analysis and review by Russel et al. looked at data of 301 studies from 100245 participants in order to find out about possible selection bias in ASD research. They reported that only 38% of studies had given sufficient information regarding intellectual ability of participants (G. Russell et al., 2019).

Moderator Analysis - Age

The other moderating variable that was explored, was the influence of age. According to the Moderator Analysis performed, age did not have an influence on ToM tasks. However, a significant effect was observed when looking at age and WCC. The Analysis showed that with increasing age, the difference in findings for WCC between ASD and TD became smaller. Since there were only eleven studies that were included for moderator analysis, the moderating effect should be interpreted with caution. However, it seems reasonable that age could have a moderating effect on WCC, especially at a younger age. One argument for the moderating effect of age could be, that especially at a very young age, findings are often based on parent reporting systems, giving the potential for bias (Miller, Perkins, Dai, & Fein, 2017). Another argument for age as a moderating variable is, that people with ASD will might have developed some kind of coping strategy throughout their life and therefore show less differences in WCC tasks, when compared to TDs. Unfortunately, the development of cognitive aspects in ASD over time has hardly been examined. There are some studies that have found an effect for a change in ToM over time, where a link between ToM and language development is hypothesized (Steele, Joseph, & Tager-Flusberg, 2003). However, to our knowledge, no study so far has observed the development of WCC over time. Hence, we can only speculate about the possible effects of age on WCC at this point in time.

Relationship between the Cognitive Constructs

Our results show independence of EF and ToM which speculatively renders EF as an unspecific symptom of developmental and neurological disorders (Hessen, Alfstad, Torgersen, & Lossius, 2018; Levit, Hachinski, & Whitehead, 2020) corroborating suggestions of a genetic overlap between developmental disorders (Antshel & Russo, 2019; Hovik et al., 2017). It is known that developmental disorders such as ADHD and ASD often co-occur and also show similarities in the expression of symptoms (Brookman-Frazee, Stadnick, Chlebowski, Baker-Ericzén, & Ganger, 2018). Yet, phenomenologies are sufficiently distinct to separate the two as distinct disorders associated with own diagnostic categories (Antshel & Russo, 2019). As previously mentioned ASD and ADHD both show impairments in EF. The characteristic subdomains of the two disorders do however differ, with people with ADHD showing the main impairment for Inhibition (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005), while the cognitive profile for EF in ASD is not yet clear (Demetriou et al., 2018).

Cognitive Profile

The autistic cognitive profile has been basis for many neurocognitive studies and is still widely discussed (Demetriou et al., 2019). Various aspects, such as genetics and neurobiological factors seem to be involved in determining the autistic phenotype. Another widely discussed aspect is the role of the neurocognitive functions such as EF, ToM, WCC, social impairment and restrictive repetitive behaviour (Demetriou et al., 2018). As mentioned previously, the Idea that the autistic cognitive profile is derived from only one origin has been challenged, due to the complexity and spectrum of symptoms (Happe et al., 2006).

A main aim of this study was to provide clarity regarding the role of EF for the cognitive profile in ASD. Probably the most accepted and largely associated cognitive construct in ASD is ToM (Jones Catherine et al., 2017). In accordance with previous research, our study showed that the main part of studies that looked at ToM in ASD, have found significant impairment in ToM when comparing ASD against a control group (Kimhi, 2014). Since ToM is so prominent in ASD, there has been a lot of effort in finding a relation between ToM and other cognitive constructs such as EF and WCC.

ToM and EF

The role between EF and ToM has been extensively examined. There are multiple arguments that an impairment in EF leads to impairments in ToM. This argument is however not generalizable to all subtypes of EF but can only be applied to some. One argument is e.g. that a certain amount of set shifting ability is necessary in order to successfully complete a ToM task. The underlying idea is that, only when set shifting ability is working adequately, the individual is able to shift its perspective from one person to another, as is required by ToM tasks (Antshel & Russo, 2019). The other claim that has been proposed is that Working Memory needs to be adequately functioning in order to succeed at ToM tasks. Only when one is able to hold someone else's thought in mind, one can also take another's perspective (Bull, Phillips, & Conway, 2008). Neuroimaging studies have shown that ToM and EF seem to activate similar neural mechanisms. However, the cortical areas activated for ToM and EF tasks are not entirely overlapping, therefore still leaving room for the argument of the independence of the two cognitive Constructs (Wade et al., 2018). Also, it seems that the direction in which the two Constructs relate on each other is unidirectional, meaning that only impairment in EF leads to an impairment in ToM. However, the findings regarding this claim have been very scarce and therefore the unidirectional approach should be interpreted with caution (Wade et al., 2018). Yet, another very important point in viewing the relationship between ToM and EF is that most findings have been observed in people with different types of neurological- and developmental disorders (Hessen et al., 2018; Levit et al., 2020), making a clear point in stating that the occurrence of EF impairment cannot be regarded as specific for ASD. These observations are congruent with our findings and further clarify the notion that impairment in EF should be seen as an unspecific complex of symptoms of developmental- and neurological disorders and cannot be considered as specific for a certain developmental disorder.

WCC and EF

Since EF and WCC both show impairment in ASD, it was tried to find a relationship between them in previous studies (Pellicano, Maybery, Durkin, & Maley, 2006). The underlying idea of a possible connection between EF and WCC comes from the idea that EF performance determines WCC performance. An important subdomain of EF that seems to play a crucial role for WCC is planning (Laurent Mottron et al., 1999). Data from figure drawing tasks, revealed that under circumstances that presume a certain amount of planning ability, people with ASD take more time to draw the figure than TDs (Leevers & Harris, 1998). Hence, the findings indicate a possible relationship between poor performance in planning tasks and tasks of WCC. Another relationship between EF and WCC is claimed to be found between performance in Working Memory and WCC (Laurent Mottron et al., 1999). As previously mentioned, people with ASD often show above average performance at EFT and Block Design Tasks (Frith, 2003). Regarding an executive interpretation of this phenomenon it has been proclaimed, that a limited capacity of Working Memory, as often observed in ASD, only allows for a limited amount of complexity of parts that can be held in mind. Therefore, making it harder for people with ASD to perceive the whole, more complex, picture, instead of only perceiving its parts (Laurent Mottron et al., 1999). A third claim regarding the connection of EF and WCC in ASD is that a limited amount of Flexibility, as often observed in ASD, contributes to weaker performance in CC tasks. The idea is that, in order to switch from a local to a global picture one needs to be able to switch sets. Since a deficiency in set shifting is an often observed phenomenon of ASD it seems reasonable, that an impairment might also lead to WCC (Laurent Mottron et al., 1999).

However, as also became noticeable in our study, research regarding a relationship between EF and WCC has been very scarce (Pellicano et al., 2006). There are some experimental studies that have looked for an interaction between the two constructs, but hardly any summarising overviews exist. Therefore, findings regarding a correlation between EF and WCC need cautious interpretation.

Conclusion

This meta-analysis and regression showed that there is an overall impairment in ASD for all classical cognitive constructs, EF, ToM and WCC. Although all EF subdomains were significantly impaired in the ASD group with a moderate effect size, EF did not show any significant association with the autism-specific domain of ToM. Therefore, these results question the relevance of EF for the autism-specific cognitive profile.

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