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ARTICLES

Cognitive Training of Attention and Executive Functions in Children With Autism: Meta-Analysis

Treinamento Cognitivo de Atenção e Funções Executivas em Crianças com Autismo: Metanálise

Entrenamiento Cognitivo de la Atención y Funciones Ejecutivas en Niños con Autismo: Meta-Análisis

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Abstract: Attention and executive functions are skills commonly impaired in children with autism spectrum disorder. However, the effectiveness of cognitive training in this population remains uncertain. Thus, this meta-analysis aimed to evaluate the effectiveness of available cognitive trainings in improving trained skills and those not directly trained. The search in SCOPUS, ScienceDirect, PubMed databases and reference lists resulted in seven articles analyzed for their quality, risk of bias and effect sizes, covering 213 participants. The effect size was medium for the trained cognitive domains, with greater effects for attention cognitive training. Untrained skills also benefited, especially social interaction and communication. Future studies are needed to assess the effects of cognitive training on other skills, such as academic performance, and in specific components of the executive functions, as inhibitory control.

Keywords: cognition; autism; children; intervention; meta-analysis.

Resumo: Atenção e funções executivas são habilidades comumente prejudicadas em crianças com transtorno do espectro do autismo. No entanto, a eficácia do treinamento cognitivo nesta população permanece incerta. Assim, esta metanálise teve como objetivo avaliar a eficácia dos treinamentos cognitivos disponíveis para melhorar as habilidades treinadas e aquelas não treinadas diretamente. A busca nas bases de dados SCOPUS, ScienceDirect, PubMed e listas de referência resultou em sete artigos analisados quanto à qualidade, risco de viés e tamanhos de efeito, abrangendo 213 participantes. O tamanho do efeito foi médio para os domínios cognitivos treinados, com maiores efeitos para treinamentos cognitivos da atenção. Habilidades não treinadas também se beneficiaram, especialmente a interação social e a comunicação. Estudos futuros são necessários para avaliar os efeitos de treinamentos cognitivos em outras habilidades, como as acadêmicas, e em componentes específicos das funções executivas, como o controle inibitório.

Palavras-chave: cognição; autismo; crianças; intervenção; metanálise.

Resumen: La atención y las funciones ejecutivas son habilidades comúnmente afectadas en niños con trastorno del espectro autista. Así, la efectividad del entrenamiento cognitivo en esta población sigue siendo incierta. Por lo tanto, este metanálisis objetivó evaluar la efectividad de los entrenamientos cognitivos disponibles para mejorar las habilidades directamente entrenadas y no entrenadas. La búsqueda en las bases de datos SCOPUS, ScienceDirect, PubMed y listas de referencias resulto en siete artículos analizados en cuanto a calidad, riesgo de sesgo y tamaño del efecto, que abarcan 213 participantes. El tamaño del efecto fue medio para los dominios cognitivos entrenados, con efectos mayores para el entrenamiento cognitivo de la atención. Las habilidades no entrenadas también se beneficiaron, especialmente la interacción social y la comunicación. Se necesitan estudios futuros para evaluar los efectos del entrenamiento cognitivo en otras habilidades, como las académicas, y en componentes específicos de las funciones ejecutivas, como el control inhibitorio.

Palabras clave: cognición; autismo; niños; intervención; metaanálisis.

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Autism spectrum disorder (ASD) refers to a childhood-onset neurodevelopmental disorder whose main characteristics are deficits in communication/social interaction and repetitive and restrictive behavioral patterns (American Psychiatry Association, 2013). ASD refers to a generic name for a continuum of cognitive, behavioral, social, physical and learning deficits (Kerns *et al.*, 2016). Children on the spectrum face constant and diverse cognitive and behavioral challenges, so there is a demand for effective interventions that improve underlying cognitive skills crucial to mitigating the difficulties associated with this disorder (Kerns *et al.*, 2016; Powell *et al.*, 2016).

Despite the variability of ASD presentations, attention and executive functions (EF) are among the cognitive abilities known to be in deficit in children on the spectrum. Attention, defined as the ability to appropriately allocate processing resources (Mannarelli *et al.*, 2019), is shown to be impaired in children with ASD. According to a literature review that included experimental studies with a variety of neuropsychological tasks and different modalities of imaging exams, children with ASD present important deficits in attention abilities, including selective, sustained and alternating attention (Allen & Courchesne, 2001).

Specifically about EF, recognized as self-regulation skills that allow task planning and intentional cognitive action (Willoughby *et al.*, 2019), it is pointed out that their development in children with ASD is also impaired. Exploratory studies such as Zhang's *et al.* (2020a) and also a meta-analysis study (Habib *et al.*, 2019), revealed that scores in phonological and visuospatial domains of working memory were significantly lower for individuals with ASD compared to typically developed controls. Children with ASD also showed poor performance in cognitive flexibility, according to shifting tasks (Albein-Urios *et al.*, 2018). Similar results are observed for inhibitory control. According to Schmitt *et al.* (2018), relative to controls, individuals with ASD had reduced accuracy on stop-signal test, involving failures to strategically delay behavioral response onset. In this sense, recent studies revealed considerable overall executive deficits in children with ASD (De Vries *et al.*, 2015).

Accordingly, attention deficit hyperactivity disorder (ADHD) is a comorbid diagnosis of ASD marked by deficits in attention and EF components, estimating that 95% of children with ASD present them (Kerns *et al.*, 2016). It is noteworthy that attention and EF are involved in cognitive development, in general, and in the development of social, emotional and academic skills (Miranda *et al.*, 2017). Thus, it is understood that EF components and attention with atypical development contribute to the symptoms of ASD, being essential the development of effective interventions aiming these processes (Leung *et al.*, 2016; Miranda *et al.*, 2017).

It is understood that improvements in aspects of attention and EF can decrease the severity of ASD symptoms, reducing associated secondary deficiencies such as mental health problems, improving behavioral and academic functioning, as well as possibly increasing the results of other interventions applied concurrently (Rueda *et al.*, 2010). However, despite the relevance, few direct cognitive interventions have been developed for children with ASD (Kerns *et al.*, 2016; Powell *et al.*, 2016), with a prevalence of interventions, albeit in small quantities, centred on behavioral and educational perspectives and explicitly addressing aspects of communication/social interaction and the reduction of repetitive behaviors (Reichow, 2012).

Thus, it is known that the literature on cognitive training (CT) for children with ASD is still limited, and the effectiveness of strategies and programs used in this population remains uncertain (Kerns *et al.*, 2016). In this context, this meta-analysis aims to present the cognitive training of attention and EF components available to children with ASD and assess their effectiveness. By doing this, we seek to answer some crucial questions, namely: do cognitive training improve the cognition of children with ASD? If so, which cognitive domains benefit most? Does the improvement transfer to aspects other than those directly trained? It is noteworthy that evaluating whether currently applied training programs can improve the cognition of children with ASD, discriminating more and less responsive cognitive domains, will be useful in expanding the application of cognitive training in this population and in designing new, accessible and effective intervention programs.

Method

It is a systematic literature review study with meta-analysis performed by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

Search strategies and information sources

In June 2021, the SCOPUS, ScienceDirect and PubMed databases were consulted using combinations of the terms autism OR autistic OR asperger AND "cognitive training" OR "brain training" OR "cognitive remediation". The search was restricted, including articles published in English, Spanish and Portuguese, without time limitation.

Eligibility Criteria

Eligibility was initially assessed based on the filtering mechanisms available in the consulted databases, considering the following inclusion criteria in this first screening: (1) articles; (2) written in Portuguese, English or Spanish; (3) already published (not in press); and (4) reporting results of empirical studies. After this first selection, the potential studies were evaluated as to their inclusion or not based on the titles and abstracts of the articles, applying the following inclusion criteria: (5) that report interventions; and (6) who have participants with a mean age of 13 years or less. Based on titles and abstracts, the following studies were excluded: (1) that do not refer to the theme "cognitive training in children with ASD"; (2) theoretical studies; (3) with participants in other age groups; (4) in other languages; and (5) repeated (counting the repeated only once). After the full reading of the remaining articles, the other exclusion criteria were considered, namely: (6) that do not analyze the results of cognitive training separate from other interventions performed concurrently; and (7) that do not present mean and standard deviation data in their results (which does not allow the calculation of the size of the effects found).

Quality and risk of bias analysis

After selecting the articles, their quality was analysed using an adapted version of the Physiotherapy Evidence Database (PEDro) (Maher *et al.*, 2003). It stands out that this scale was applied because it is not as rigid as those used in medical laboratory studies, which differ from studies in psychology due to the possibility of more objective control of variables. In this study, five items of the scale were considered, namely: specified eligibility criteria, random allocation into groups, similar groups at baseline, blinding of the researchers and statistical comparisons between groups. In addition to quality analysis, studies were also assessed for risk of bias using the Cochrane's Collaboration's risk of bias tool (Higgins & Green, 2008). The following aspects are considered in the tool: description of the method used for allocation, blinding of participants, blinding of researchers, completeness of data and results, selective results reported and other sources of bias. The studies were classified as low risk of bias (scores between 0 and 2 points), medium (between 3 and 4 points) and high (between 5 and 6 points).

Effects Size analysis

The effect sizes were calculated for each outcome reported in studies considering the experimental groups in pre and post-intervention periods (pre-test and post-test). In cases where lower scores represented a gain in skill (e.g., decrease in the number of errors or in response time) the corresponding inversion was performed. Studies that presented more than one score for the same variable (e.g., scores for selective attention, attention control, sustained attention, and general attention capacity) entered and all their effects were calculated. For interpretation, insignificant (<0.19), small (0.20-0.49), medium (0.50-0.79) and large (0.80-1.29) effects were considered (Cohen, 1988, p. 40).

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Data collection and analysis

The data collection was carried out by extracting the following information from the articles: sample size, gender, age, duration of interventions, place of study (countries), place of application of the intervention (home, school, clinic or others), trained skills (attention or EF), quality of studies, risk of bias, transfer data, limitations, means and standard deviations. It is noteworthy that when information regarding sex and age was not directly provided in the articles, the authors performed the calculation (e.g., when only the number of male participants was reported and not the percentage).

Data analysis was performed using RevMan software version 5.4.1 (The Cochrane Collaboration, 2020). The random-effects model and the standardized mean difference (SMD) were used. The heterogeneity index (I^2) was classified as: non-heterogeneous (values close to 0%), low (close to 25%), moderate (close to 50%) and high (above 75%) (Higgins *et al.*, 2003). The 95% confidence interval was calculated for each effect size. Sensitivity analysis was performed, excluding results that indicated to be outliers. If certain studies strongly affected the results, they were excluded and the analysis repeated without them. Analyzes were conducted for all outcomes combined, showing an overall effect of interventions and transfer outcomes indicated in the studies.

Results

The initial search in the databases resulted in the identification of 220 studies. Of this total, 137 were excluded based on search engine filters, 71 considering titles and abstracts and seven after reading in full, resulting in five studies. Additional articles were identified from a manual search of the reference lists of the five included articles, resulting in a further six potential studies. Subsequently, the identified papers were also filtered according to the abovementioned inclusion criteria, resulting in two more inclusions, totaling seven articles. According to PRISMA guidelines, Figure 1 provides an overview of the study selection process (Page *et al.*, 2020).

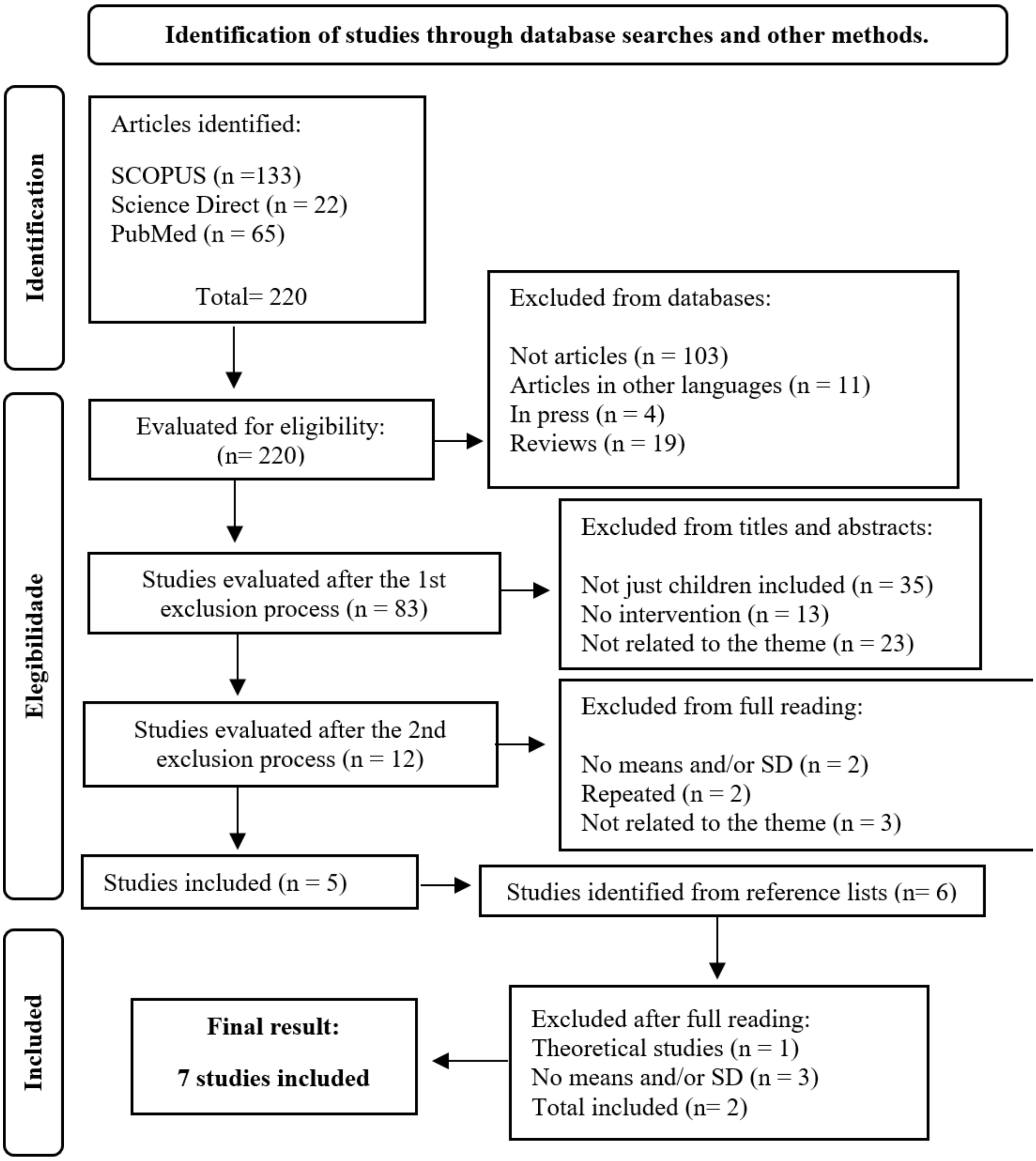

Figure 1 . *Summary of identification and selection of studies.*

Note. A single study could be excluded on more than one criterion but appears only once in the diagram.

The seven datasets included 213 participants with a mean age of 12 years, the majority being male (86%), as expected, due to the higher male prevalence of ASD in children (Zhang *et al.*, 2020b). The sample consisted of participants from Iran, Canada, Wales, Spain, the Netherlands, England and Brazil. Most studies included children with median intelligence quotient (IQ) (>80; 71% of studies), while one included children with low IQ (Powell *et al.*, 2016) and another did not report (Farrelly & Mace, 2015). As for therapeutic processes that the included children were participating during interventions or participated before, only three studies reported, these treatments being Language Therapy (Varanda & Fernandes, 2017), Academic/Behavior Support (Kerns *et al.*, 2016) and Applied Behavior Analysis (ABA; Saniee *et al.*, 2019). Most studies showed median quality on the PEDro scale, with a mean score of 3.85 (from 0 to 5 points). The risks of bias were predominantly low, averaging 2.16 points (from 0 to 6 points). The general characteristics of the included studies are shown in Table 1 below.

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Table 1. *General Characteristics of the Included Studies*

Study (Year)	Country	N	M. Age	IQ	ASD	Treatment	M. %	R. B	Q
Saniee *et al.* (2019)	Iran	13	6.2	>80	High F.	ABA	84	1	4
Kerns *et al.* (2016)	Canada	17	8.17	>80	High F	Academic Behavioral Support	57	4	2
Powell *et al.* (2016)	Wales	17	6.8	<80	Medium to Severe	Not clear	88	2	4
Bravo-Alvarez & Frontera-Sancho (2016)	Spain	15	12	>80	Asperger	Not clear	93	2	4
De Vries *et al.* (2015)	Nether-lands	121	10.5	>80	Not clear	Not clear	89	0.5	5
Farrelly & Mace (2015)	England	20	12.7	No*	Not clear	Not clear	100	2	4
Varanda & Fer-nandes (2017)	Brazil	10	8.2	60**	Not clear	Language the-rapy	90	2	4

*Note***.** *= Does not inform; **= mean of Raven; N= sample size; Q = Study quality; M. Age = approximate mean age; M.% = approximate mean of male participants; R. Bias= risk of bias; High F= high functioning.

As for the cognitive training programs used, those in-game formats stood out (71%), such as Braingame Brian and Caribbean Quest (CQ). The training used varied in duration, ranging from less than one month (Farrelly & Mace, 2015) to six (Bravo-Alvarez & Frontera-Sancho, 2016), with weekly application frequency also variable, from one to seven times per week. Concerning the place of application of the interventions, most were the school, followed by the number of applications at home, in the research laboratory and in clinics. Table 2 presents the description of the cognitive training implemented in the studies.

Table 2. *Intervention Programs*

Study (Year)	**Trained Hab. (Format)**	**Description (Program name)**	**Local (Weekly frequency)**	**Months**
Saniee *et al.* (2019)	Cognitive Flexibility (Game)	Computer game in the form of a puzzle with changeable rules. Pieces can be combined using two rules: color and shape (Unnamed)	Home (7)	2
Kerns *et al.* (2016)	Attention and Working Memory (Game)	Five hierarchically structured tasks in adaptive format that target different aspects of attention and/or working memory. The intervention incorporates metacognitive strategies provided by a trained educational assistant (Caribbean Quest)	School (5)	2.5
Powell *et al.* (2016)	Attention (Task)	Training battery consisting of four different tasks, aimed at a combination of interference resolution, visual search, goal maintenance, and task switching (Unnamed)	School (2)	1
Bravo-Alvarez & Frontera-Sancho (2016)	Attention (Game)	Program that works through series of attention exercises that stimulate the following areas: sustained, selective, alternating and divided attention (Attention Game)	Clinic (2)	6
De Vries *et al.* (2015)	Working Memory and Cognitive Flexibility (Game)	Game that follows the character Brian and consists of working memory and cognitive flexibility training tasks (Braingame Brian)	Home (4)	1.5
Farrelly & Mace (2015)	Cognitive Flexibility (Task)	Three sessions targeting different aspects of cognitive flexibility, namely: social, with empathy skills and perspective-taking; and cognitive, with tasks including the Stroop Test and Wisconsin Card Sorting Test (Unnamed)	School (1)	0.70
Varanda & Fernandes (2017)	Cognitive Flexibility (Game)	Ludic activities aimed at training specific skills related to cognitive flexibility (Unnamed)	Research lab (1)	5.2

Regarding trained skills, cognitive flexibility stands out (57% of the studies), followed by attention (42%) and working memory (28%). The improvement obtained by cognitive training in skills not directly trained (far transfer) is evidenced in cognitive aspects such as the EF themselves (De Vries *et al.*, 2015), attention (De Vries *et al.*, 2015; Powell *et al.*, 2016) and fluency in oral reading (Kerns *et al.*, 2016); in social skills such as social interaction, adaptive social behaviors and communication (De Vries *et al.*, 2015; Saniee *et al.*, 2019; Varanda & Fernandes, 2017); in ADHD symptoms; and the quality of life of the trained children (De Vries *et al.*, 2015).

All included studies reported some significant effect of the applied cognitive training, so for effect size analysis, all measures were considered, including 19 related impacts to trained attention skills and executive functions. The general sensitivity analysis resulted in excluding an outcome as it significantly affected the group's heterogeneity, which is the measure "Look for symbols" in the study by Bravo-Alvarez and Frontera-Sancho (2016). After the exclusion, the heterogeneity and size of the overall effect were reduced, which previously represented 66% of heterogeneity and an effect of 0.83 (95% CI [0.55-1.11], $p<0.001$) started to indicate 33% heterogeneity with an effect of 0.72 (95% CI [0.52-0.92], p<0.001). Thus, after removing the measure, there was an average overall effect size with low heterogeneity (Figure 2).

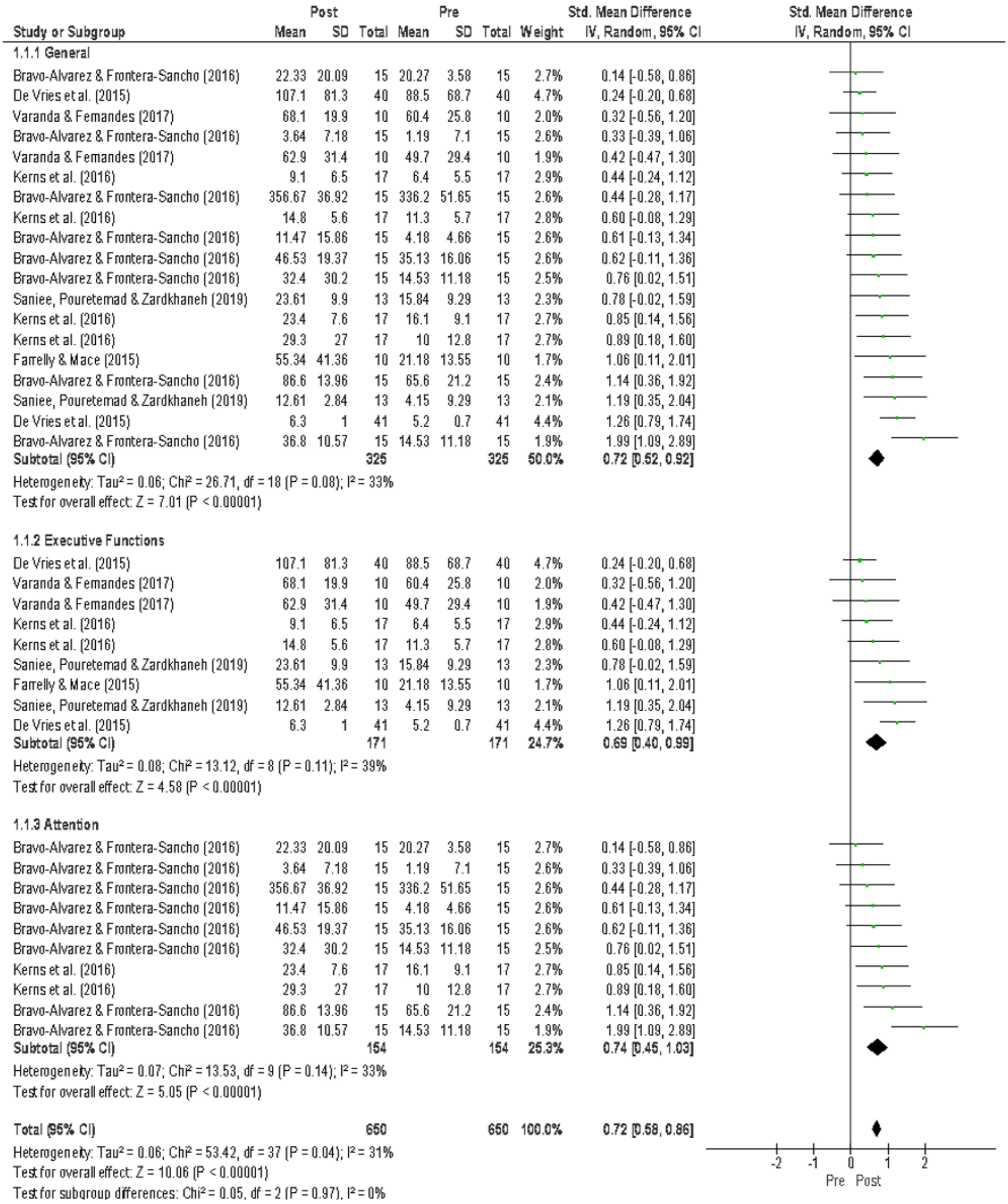

Figure 2. *Overall efficacy of interventions on all cognitive outcomes*

Note. SMD = standardized mean difference; SE = standardized error.

With regard to the cognitive domains separately (Figure 2), there was a statistically significant moderate effect size for executive functions, namely cognitive flexibility and working memory, (SMD = 0.69, 95% CI [0.40-0.99], p< 0.001), with low heterogeneity (39%), as well as for selective, sustained, alternating and divided attention, which despite presenting a slightly larger effect size it was also medium (SMD= 0.74, 95% CI [0.45-1.03], p<0.001) and with low heterogeneity (33%). In Figure 3 it is possible to observe the distribution of results and a funnel plot.

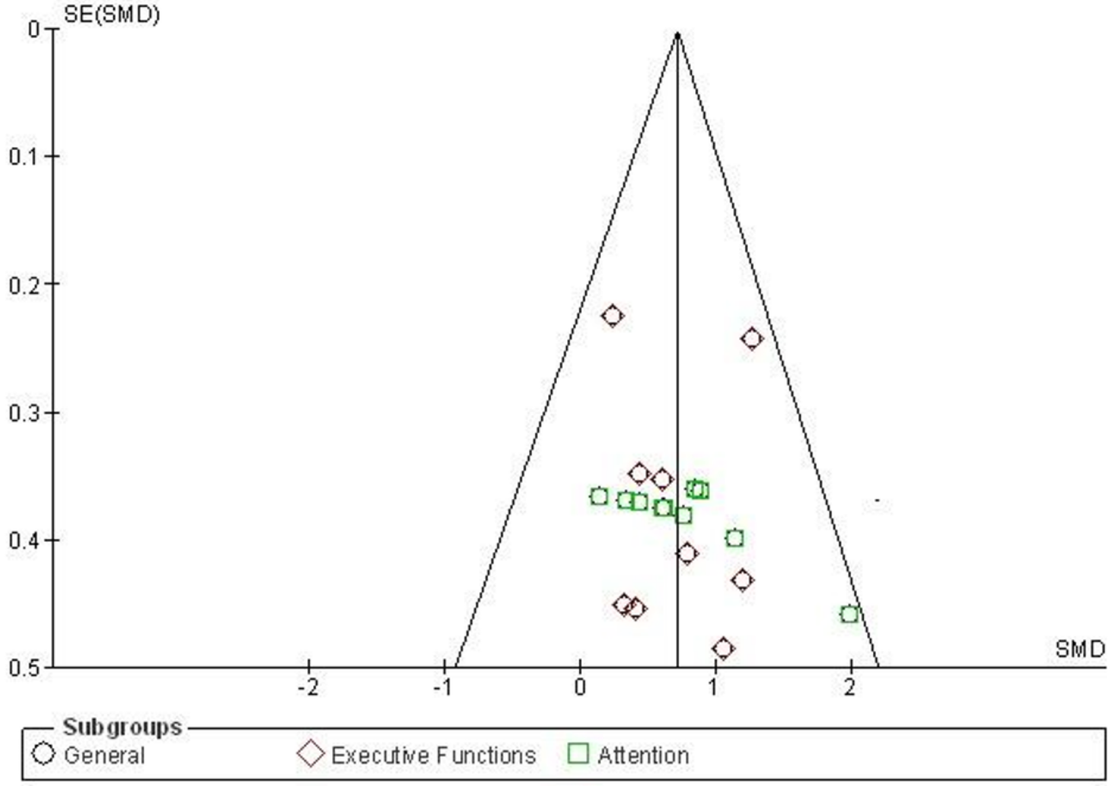

Figure 3. *Funnel plot for General Effects*
Note. SMD = standardized mean difference; SE = standardized error.

About the skills not directly trained (Figure 4), 19 effects were also included, but no need to exclude any result was verified after sensitivity analysis. A small but statistically significant overall effect size was observed (SMD = 0.40, 95% CI [0.24-0.57], p<0.001), with low heterogeneity (33%). Specifically on social interaction, it was identified medium and homogeneous effect

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size (SMD = 0.68, 95% CI [0.08-1.28], p=0.03; I^2= 0%). For the communication aspect, a large and homogeneous effect size was observed (SMD = 0.90, 95% CI [0.29-.51], p=0.004; I^2= 0%).

Study or Subgroup	Post Mean	Post SD	Post Total	Pre Mean	Pre SD	Pre Total	Weight	Std. Mean Difference IV, Random, 95% CI
2.1.1 General								
De Vries et al. (2015)	25.6	9.6	40	25.5	10	40	6.8%	0.01 [-0.43, 0.45]
Varanda & Fernandes (2017)	6.2	3.1	10	6	2.3	10	2.5%	0.07 [-0.81, 0.95]
Powell et al. (2016)	829	118	9	813	91	9	2.3%	0.14 [-0.78, 1.07]
De Vries et al. (2015)	28.6	10.8	41	27	10.8	41	6.9%	0.15 [-0.29, 0.58]
De Vries et al. (2015)	164.7	17.8	40	160.9	19.5	40	6.8%	0.20 [-0.24, 0.64]
De Vries et al. (2015)	47.8	14.1	41	44.2	15.3	41	6.9%	0.24 [-0.19, 0.68]
De Vries et al. (2015)	46	14.1	40	42.2	14.9	40	6.7%	0.26 [-0.18, 0.70]
De Vries et al. (2015)	233.3	61.3	41	216.8	61.6	41	6.8%	0.27 [-0.17, 0.70]
De Vries et al. (2015)	31.5	10.4	40	28.5	11.2	40	6.7%	0.27 [-0.17, 0.72]
De Vries et al. (2015)	164.6	22.2	41	157.6	21.1	41	6.8%	0.32 [-0.12, 0.76]
De Vries et al. (2015)	34.2	12	41	29.8	12.8	41	6.8%	0.35 [-0.09, 0.79]
Varanda & Fernandes (2017)	11.5	5.7	10	8.9	4.6	10	2.4%	0.48 [-0.41, 1.37]
De Vries et al. (2015)	233	52.1	40	197.1	53.2	40	6.6%	0.68 [0.22, 1.13]
Powell et al. (2016)	14.3	3	9	11.9	3	9	2.1%	0.76 [-0.20, 1.73]
Saniee, Pouretemad & Zardkhaneh (2019)	13.08	6.39	13	8	4.47	13	2.8%	0.89 [0.08, 1.70]
Varanda & Fernandes (2017)	13.1	4.2	10	9.2	4	10	2.3%	0.91 [-0.02, 1.84]
Saniee, Pouretemad & Zardkhaneh (2019)	13.85	6	13	8.69	4.82	13	2.8%	0.92 [0.10, 1.73]
Kerns et al. (2016)	30.8	21	17	10.2	7.5	17	3.3%	1.28 [0.53, 2.02]
Powell et al. (2016)	580	84	9	414	60	9	1.4%	2.17 [0.94, 3.39]
Subtotal (95% CI)			**505**			**505**	**89.7%**	**0.40 [0.24, 0.57]**
Heterogeneity: Tau² = 0.04; Chi² = 26.91, df = 18 (P = 0.08); I² = 33%								
Test for overall effect: Z = 4.93 (P < 0.00001)								
2.1.2 Social Interaction								
Varanda & Fernandes (2017)	11.1	5.7	10	8.9	4.6	10	2.4%	0.41 [-0.48, 1.29]
Saniee, Pouretemad & Zardkhaneh (2019)	13.85	6	13	8.69	4.82	13	2.8%	0.92 [0.10, 1.73]
Subtotal (95% CI)			**23**			**23**	**5.3%**	**0.68 [0.08, 1.28]**
Heterogeneity: Tau² = 0.00; Chi² = 0.69, df = 1 (P = 0.41); I² = 0%								
Test for overall effect: Z = 2.23 (P = 0.03)								
2.1.3 Communication								
Saniee, Pouretemad & Zardkhaneh (2019)	13.08	6.39	13	8	4.47	13	2.8%	0.89 [0.08, 1.70]
Varanda & Fernandes (2017)	13.1	4.2	10	9.2	4	10	2.3%	0.91 [-0.02, 1.84]
Subtotal (95% CI)			**23**			**23**	**5.1%**	**0.90 [0.29, 1.51]**
Heterogeneity: Tau² = 0.00; Chi² = 0.00, df = 1 (P = 0.98); I² = 0%								
Test for overall effect: Z = 2.88 (P = 0.004)								
Total (95% CI)			**551**			**551**	**100.0%**	**0.44 [0.29, 0.59]**
Heterogeneity: Tau² = 0.04; Chi² = 31.27, df = 22 (P = 0.09); I² = 30%								
Test for overall effect: Z = 5.76 (P < 0.00001)								
Test for subgroup differences: Chi² = 2.97, df = 2 (P = 0.23), I² = 32.6%								

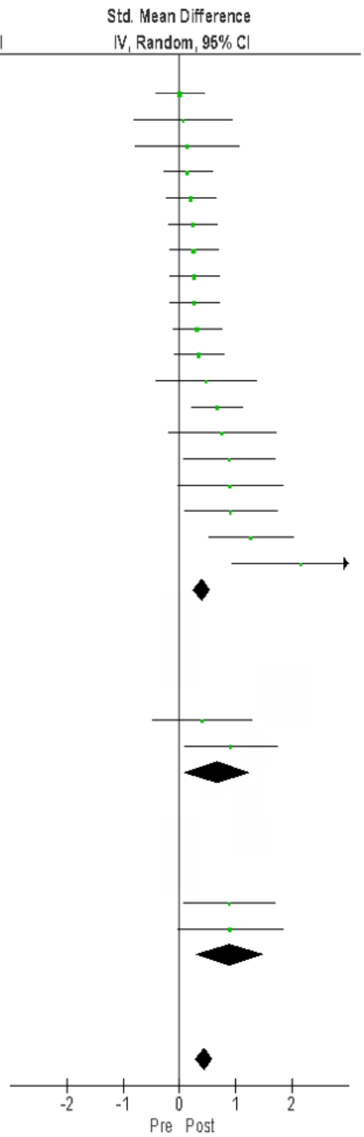

Figure 4. *Transfer to skills not directly trained (far transfer).*

Note. SMD = standardized mean difference; SE = standardized error.

Discussion

This meta-analysis study aimed to expose cognitive training programs for children with ASD, identifying their effectiveness for trained skills, specifically attention and executive functions, and their transfer to non-directly trained domains. Similar to previous meta-analyses with other populations, the prevalence of studies of reasonable quality and with low risk of bias was evidenced (e.g., Sala & Gobet; 2017; Soveri *et al.*, 2017). Among the training programs used, those in-game formats stood out, including motivational elements and train cognitive domains presenting activities with levels of difficulty adaptable to the child's abilities.

Computerized cognitive trainings (CCT), such as Braingame Brian, allows that the calibration of difficulty to be done by algorithm, ensuring that the challenge matches the children's range of ability and that they work close to their limits, advancing as the child increases the ability, which can ensure more gains after training (Phillips *et al.*, 2016). In addition to interventions in an adaptive format, training that incorporates metacognitive strategies with the help of educational assistants, such as the Caribbean Quest (Kerns *et al.*, 2016), should be highlighted. Metacognitive strategies, defined as mental actions associated with planning, monitoring and control capabilities, are known to facilitate the recovery of knowledge already acquired, enhancing the quality of learning (Nicolielo-Carrilho & Hage, 2017) and, specifically in the context of training, the effectiveness of the intervention in promoting cognitive enhancement.

The training proved to be promising for all trained skills, with statistically significant effect sizes from moderate to high and low heterogeneity, allowing greater reliability in the analyses performed. Considering the low variability of the identified effect sizes, it is possible to understand that the interventions were efficient regardless of the application place, type, frequency and total training time. This result is important because it recognizes the effectiveness of other available non-pharmacological intervention modalities, in addition to those based on intensive and early behavioral training, which are more widely disseminated (Powell *et al.*, 2016).

However, this result differs from that observed in studies with other populations, such as typically developing children, adults and elderly, who identified smaller effect sizes and high levels of methodological heterogeneity (e.g., Lampit *et al.*, 2014; Walton *et al.*, 2018). This difference may be linked to the greater adaptability of interventions to the child's abilities and the more active role of the applicator of interventions in the specific context of children with ASD. In the study developed by De Vries *et al.* (2015), for example, despite the training activities being carried out at home, there was weekly monitoring of the progress with the children's parents, which does not commonly happen in interventions aimed at children considered typical.

Concerning the cognitive domains separately, it was evidenced that attention training had slightly more significant effects than those directed to EF. However, both were moderate and significant, confirming cognitive training as an efficient non-pharmacological alternative for application in clinical, school and home contexts. After the training of attention in children with ASD, significant changes were observed in the modalities of sustained, alternate and divided visual attention and in all the attention subsystems evaluated, verifying a substantial reduction in errors and task execution time (Bravo-Alvarez & Frontera-Sancho, 2016; Kerns *et al.*, 2016; Powell *et al.*, 2016). The implications of these results are considerable, as the abnormal distribution of attentional resources evidenced in this population can be harmful, among other things, to the formation of attachment between parents and children and is associated with socio-emotional deficits that can be particularly distressing for families of children with ASD. Thus, successful interventions that can improve this cognitive ability are essential (Allen & Courchesne, 2001).

As for EF, improvements in performance in working memory tasks, such as the Corsi Block Test and digit tasks; and cognitive flexibility tests, such as the Wisconsin Card Sorting Test (WCST) and the Flexibility Scale (BFRS-R), were evidenced (De Vries *et al.*, 2015; Farrelly & Mace, 2015; Varanda & Fernandes, 2017). The improvement of executive skills was observed, especially in the increase of correct answers in memorization tasks, the reduction of perseverative errors in change/shift tasks, and the decrease in response times.

These results have important implications, given that deficits in executive functions contribute to social and non-social symptoms of ASD, such as the emission of restricted, repetitive behaviors and perseverative errors, linked to low cognitive flexibility; and deficits in the ability to store, monitor, update and select socially appropriate responses, linked to working memory and inhibition (Leung *et al.*, 2016). Thus, efficient interventions are needed to improve the performance and quality of life of this population. However, despite considering the importance of inhibitory control in children with ASD (Robinson *et al.*, 2009), no study has presented a cognitive training that directly encompasses and assesses this executive function.

About the improvement caused by cognitive training in skills not directly trained, the far transference, a small but statistically significant effect was observed with low heterogeneity. Such a transfer result implies recognizing the possibility of generalizing the specific effects to domains that exceed those trained (Sarzyńska *et al.*, 2017), which guarantees the verification of the effects not only in the scores of the attention and EF tests but in the children's performance in other activities. In this sense, effects of cognitive training on quality of life, oral reading fluency, reduction of repetitive and stereotyped behaviors and ADHD symptoms were verified (De Vries *et al.*, 2015; Kerns *et al.*, 2016; Varanda & Fernandes, 2017).

Due to the low number of studies, the analysis by distant transfer skills was only possible for aspects of social interaction and communication, which were presented in two studies each. Social interaction was significantly affected by the cognitive training used in the studies, with a moderate and homogeneous effect size. As for communication, the effect size was large and homogeneous (Saniee *et al.*, 2019; Varanda & Fernandes, 2017). Such results can be explained by the fact that deficits in the trained functions are associated with socially maladaptive behaviors that impact self-control and social activities more broadly in children with ASD (De Vries *et al.*, 2015).

In summary, the results of this meta-analysis suggest that cognitive training of attention and EF for children with ASD can be considered promising, generating gains for both directly trained and untrained skills, with the overall effect size of interventions being moderate to high, statistically significant and with no low effect variability. However, the present study has some limitations that deserve attention. First, although we searched for literature in relevant databases and consulted reference lists without time limitations, the research was restricted to the databases used and the languages included. The low number of articles, as well as the inclusion of pilot studies (e.g., Farrelly & Mace, 2015; Powell *et al.*, 2016), are also limitations, mainly associated with the small number of participants included in the analyzes and the lack of control groups. The identified results cannot be generalized to children with low IQ, as most studies have included participants with a median IQ. Furthermore, we considered the junction of different scores for different types of attention and EF, because of the reduced number of studies and the impossibility of carrying out specific analyzes (e.g. separate analysis for selective attention, working memory, etc), so that with the conduction of new studies about these skills it will be necessary to carry out a meta-analysis that considers analyzing specific components of attention and EF separately.

Additionally, the availability of few studies did not assess far transfer effects from training to academic skills, which, according to review studies with other populations (e.g., Sala & Gobet, 2017; Söderqvist & Bergman Nutley, 2015), are affected by interventions in cognitive functions. However, as shown in the results of this study, participants from different parts of the world were included, and a considerable number of effects were analyzed, revealing low heterogeneity even considering various measures of cognitive assessment, which allows greater reliability in the results.

Conclusions and Future Implications

Returning to the questions raised in the introductory topic, this meta-analysis revealed that attention and EF training programs can be considered promising in improving the cognition of children with ASD in both cognitive domains explored, emphasising attention, whose intervention programs had larger effect sizes. As for the questioning about the transfer of the improvement caused by the training to other aspects than those directly trained, it became evident that the implemented interventions caused significant effects in untrained elements aspects, such as social interaction, communication and quality of life.

Thus, it was observed that cognitive training interventions help reduce the complexity and intensity of difficulties and symptoms in children with ASD and can lead to better social and behavioral functioning. Future studies with larger samples and control groups are needed to assess the effects of cognitive training on the skills highlighted here and others not yet explored, such as inhibitory control and academic performance. In addition, studies that include children with more significant intellectual impairments are needed to assess the effectiveness of attention and EF training in this population.

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