Interventions targeting core attention functions in children with autism: A Literature Review

Abstract

While atypical attention is not a defining component of the autism diagnosis, it is often linked to autism in research. As such, attention training has the potential to not only improve attention in autism but also improve broader autism symptoms. The aim of this systematic literature review was to identify evidence-based attention training programs for infants, children and adolescents aged 18 and younger with autism, focusing on core attention skills. Results indicated that although there is a limited number of studies with regard to intervention programs on improving core attention functions in autism at this time, the majority of them had a positive impact on attention, autistic symptoms but academic performance as well, that justify the need for future investigation.

Key words: autism, core attention training, autistic symptoms, academic performance, intervention programs

Introduction

Attention is broadly defined as information processes that mediate perceptual selection (Colombo & Cheatham, 2006). Posner and Petersen (1990) and Petersen and Posner (2012) have argued that attention consists of three functionally independent attention networks: the alerting, orienting, and executive control networks. The alerting network (sustained attention) allows the individual to maintain a state of alertness and sustain attention to a specific stimulus; the orienting network (selective spatial attention) directs attention to specific sensory stimuli and locations; and the executive control network (attention control) allows the resolution of conflicting attentional information. The current systematic review was based on the aforementioned attention model. In order to distinguish those three functionally independent attention networks from joint attention, we named them core functions of attention, thus serving the purpose of our review. Because attention is the mechanism through which we view our world, thereby determining what information we process and respond to, an early-developing disorder, such as Autism Spectrum Disorder (ASD) that interferes with attention may have far reaching effects on cognitive development (Fischer et al., 2013).

Autism spectrum disorder (ASD) is a behaviorally defined developmental disorder diagnosed on the basis of impairments in the domains of social communication and repetitive and stereotyped behaviors (American Psychiatric Association, 2013).

Difficulties in attention have often been considered to be associated with the disorder (Keehn et al., 2013; Mayes & Calhoun, 2007). A recent review reports that deficits in attention disengagement and orienting in ASD are evident in the first year of life and persist into adulthood (Sacrey et al., 2014). Data coming from eye-tracking studies in young infants suggest that visual attention in people with ASD is driven by atypical saliency, especially in relation to stimuli that are usually considered socially salient, such as faces (Wang et al, 2014). Compared to matched controls, children with ASD had a stronger image center bias regardless of object distribution, reduced saliency for faces and for locations indicated by social gaze, yet a general increase in pixel-level saliency at the expense of semantic-level saliency (Wang et al, 2015). Furthermore, ASD children and teens are slow to initiate saccades and are less accurate and require more saccades to reach a target (Keehn et al., 2010; Miller et al., 2014). In a series of eye-tracking studies with 338 toddlers, Constantino et al (2017) have found a strong genetic control of attention to social scenes. Moreover, they have found that the characteristics that are the most highly heritable, preferential attention to eye and mouth regions of the face, are also those that are differentially decreased in children with autism. These attention deficits may affect early social development particularly by disrupting joint attention (Schietecatte et al., 2012; Mundy et al, 2007), regulation of social emotional arousal (Garon et al., 2009; Keehn et al., 2013) and flexibility in behaviour (Townsend et al., 2001; Senju et al., 2004). Besides, children with ASD are often reported to have difficulties in sustained attention (Chien et al., 2015; Murphy et al., 2014), in switching attention between tasks (Reed, Watts, & Truzoli, 2013; Wallace et al., 2016) and demonstrating inhibition response problems (Hopkins, Yuill, & Branigan, 2017), which can seriously affect their school performance (Keen et al., 2016; May et al., 2015).

Since disruption of attention is one of the earliest and most persistent symptoms in autism and is highly subject to improvement with training (MacSween, 2017; Sarzyńska, et al., 2017), it is an important target for intervention. The purpose of this review was to systematically review evidence regarding such interventions on core functions of attention for individuals aged 18 and younger with ASDs. Results are firstly synthesized by sample characteristics, research design, core type of attention targeted, type of intervention, intervention setting and duration of the program, including time length of sessions and frequency. Secondly, outcome measures and their type (subjective or objective or both), near and far transfer effects, effect size, follow-up measures, dropout rate and fidelity of implementation are incorporated as well.

Method

Selection procedures

To locate articles, we electronically searched PsycINFO, Scopus and ERIC (Education Resources Information Center) published only in the English language from January 2000 to December 2019. We used full and truncated versions and combinations of 8 search terms and 18 limiting terms. The precise Boolean phrase is included as Figure 1.

Search terms
Autis* OR "autism spectrum disorder" OR "autism spectrum condition" OR "ASC" OR "ASD" OR Asperger* OR "PDD*" OR "pervasive developmental disorders" And "Visual attention" OR "auditory attention" OR "attention training" OR "attention evaluation" OR "attention intervention" OR "attention assessment" OR "cognitive training" OR "response inhibition" OR "inhibitory control" OR "distractor inhibition" OR "orienting attention" OR "attention orienting" OR "task shifting" OR "attention shifting" OR "attention switching" OR "task switching" OR disengagement" OR "joint attention

Figure 1. Boolean search terms
* Is used in Boolean searches as a wildcard character that allows alternative forms or words to be captured

Inclusion /Exclusion Criteria

We used a two-phase process to determine inclusion or exclusion of studies. Phase 1 included two stages of reviewing titles and abstracts and coding according to inclusion and exclusion criteria. Phase 2 included full text review and subsequent selected feature coding.

Phase 1: Title and abstract review. Inclusion criteria were:

(a) studies included at least one person with a diagnosis of ASD, Pervasive Developmental Disorders, autism, Asperger's syndrome,

b) the age range of autistic participants should be between 0 to 18 years old (at least one of the participants to fall within this age range),

c) studies which involved individuals at high risk of autism (e.g., siblings) would only be included if they had a longitudinal design,

d) core attention skill (sustained attention, selective spatial attention, attention control, temporal attention, unspecific attention) should be a variable in the study,

e) studies which involved intervention or part of the intervention or one area of finding on core attention,

f) peer-reviewed empirical studies, book chapters, literature reviews and meta-analyses were included, and

g) in terms of reviews and meta-analysis, these were included only if core attention was the main focus of the paper.

We excluded studies:

a) not including interventions (e.g., where the focus is on measuring attention rather than applying an intervention).

b) studies involving interventions solely on joint attention,

c) studies involving exclusively adults with autism,

d) not involving human beings (e.g., monkeys),

e) involving participants with neurodevelopmental disorders, not being clear whether they had autism,

f) involving non-ASD participants (even if the syndrome has similarities with autism, such as Rett syndrome or Fragile X),

g) involving non-clinical cohorts (i.e., referring to the broader autistic phenotype),

h) drawing conclusions about attention in autism while this had not been measured in the study, and

i) medical or genetic studies (i.e., measuring the effects of drugs/substances on attention).

Stage 1: The initial search of key terms through the electronic search of databases yielded 997 studies, after checking for duplicates. Two researchers from two separate institutions reviewed each title and abstract to determine if each article met the initial inclusion criteria. If there was disagreement among the two researchers on whether or not a study should be included, they met to discuss the title and abstract and came to consensus on whether the article met initial inclusion criteria. 567 articles were identified and moved to the second stage. The second stage included screening of titles and abstracts based on second level criteria which were: a) exclusion of studies not including interventions and b) exclusion of studies involving interventions solely on joint attention. If the inclusion or exclusion criteria were not clear from the title or abstract, the study was moved into Phase 2. After titles and abstracts were scanned, 538 studies were excluded. Finally, 29 articles met the inclusion criteria for full text review.

Phase 2: Full text review. Of the 29 studies identified for full text review, 16 were excluded with reasons: five were reviews not related to interventions on core attention types, four studies were related to autistic behaviours without measuring attention, two studies were in French language, although the abstracts were in English, one study did not measure attention, one was a book chapter on joint attention, one was a study protocol with no results, one was a discussion article and one was a book chapter that could not be accessed. This resulted in a total of 13 studies to be coded for selected features in the current review (see Figure 1, Literature Review Flowchart).

Interrater reliability on full text inclusion/exclusion criteria

Two researchers reviewed independently each of the 29 studies to ascertain their inclusion/exclusion based on the criteria above. There was full agreement across the two researchers (i.e., full consensus).

Selected feature coding

Coding procedures included coding for the following:

- sample characteristics, including sample size, age range, gender, existence of comorbidity and ASD severity
- study design, including the type of study design, the research design used, type of control group, whether groups were matched at baseline, type of intervention, type of core attention, intervention setting, intervention nature (one-to-one or groups), as well as reporting who delivered the intervention and the duration, number of sessions and overall time,
- outcome measures, reporting whether they were subjective or objective, if improvement, near and far transfer effects were documented and finally reporting follow-up measures, if any
- effect size
- feasibility data related to dropout rate and fidelity of implementation

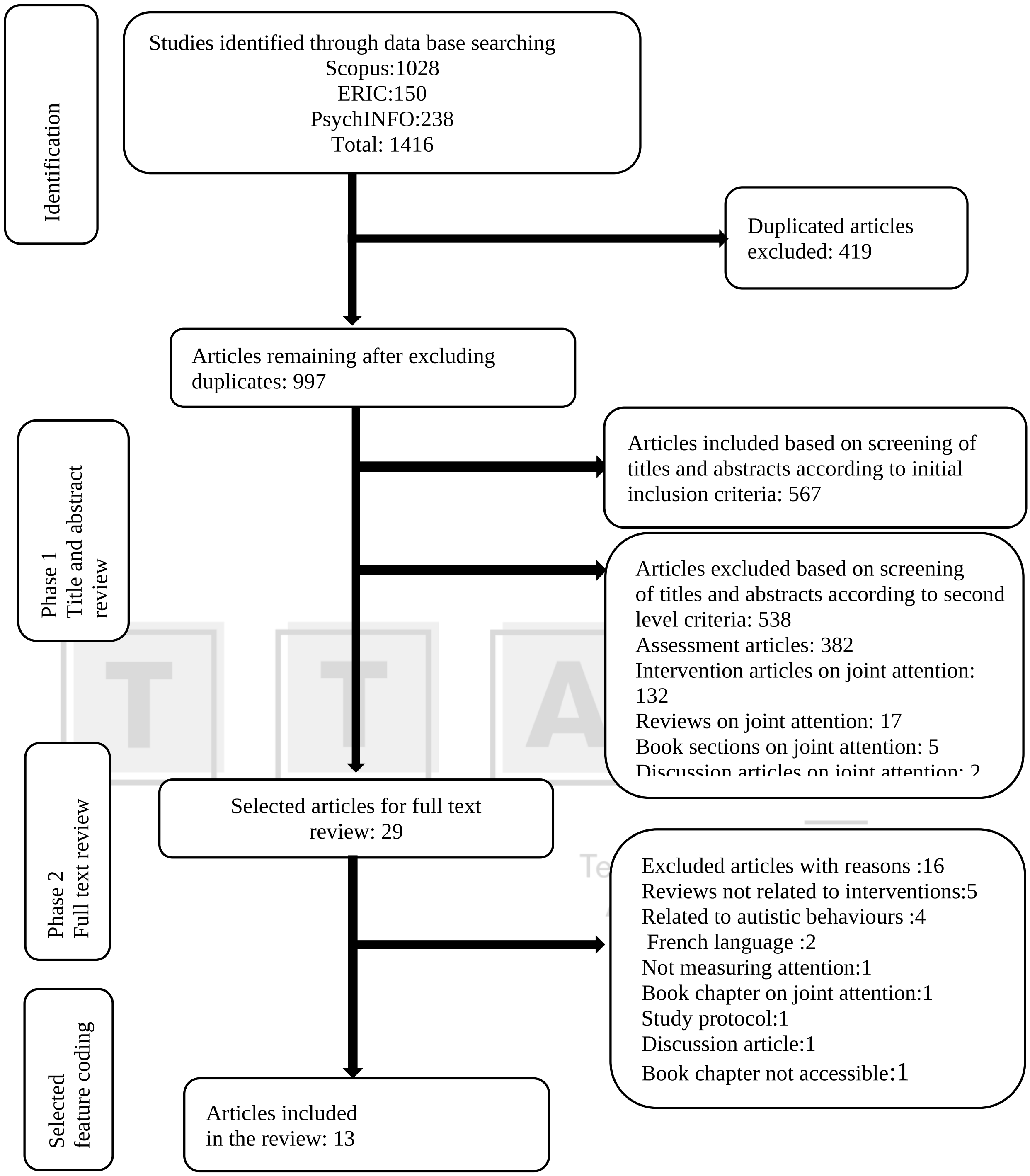

Figure 1: Literature Review Flowchart

Results

Among 1416 articles located for full analysis in the current review, 13 studies met inclusion criteria and addressed interventions on core attention types in individuals with ASD (Fig. 1).

Participant Characteristics

All studies together included a total number of 247 participants, out of which 211 were males and 36 were females. The youngest participant was 3 years and 2 months and the oldest was 17 years. All studies included participants with a diagnosis of ASD or Pervasive Developmental Disorders Not Otherwise Specified (PDD-NOS), thus meeting our inclusion criteria. In seven of the 13 studies (54%), participants had a comorbid intellectual disability (ID), whereas in four studies participants did not. In two studies ID was not mentioned, with one of them including 10 participants with Attention-Deficit/Hyperactive Disorder (ADHD) combined with Developmental Coordination Disorder (DCD) and two participants with combined ADHD and Pervasive Developmental Disorders (PDDs). Moreover, ASD severity ranged from mild to severe in the participants of 8 studies, whereas ASD severity was not specified in 4 studies. Finally, only one study included high functioning participants (see Table 1).

Table 1. Sample characteristics

Author	Year	Group/ case study	Sample size	Age Range	Gender / Sex	ID and/ or another comorbidity	ASD severity
Chan et al.	2013	group	40	6-17years	36M-4F	30% of the participants with ID/3 participants with PPD-NOS	not specified
De Vries et al.	2015	group	90	8-12years	82 M - 8 F	without ID or another comorbidity	not specified
Powell et al.	2016	group	17	3 - 9years	15M-2F	ID	severe to less severe
Spaniol et al.	2017	group	15	6-10years	12M-3F	without ID or another comorbidity	mild to moderate
Tse et al.	2019	group	40	10-11years	32M-8F	ID	Severe
Chan et al.	2011	case	1	9years and 5 months	1M	ID	low functioning
Chukoskie, Westerfield, & Townsend	2017	case	8	10-17years	5M-3F	without ID or another comorbidity	mild to severe
Cosper et al.	2009	case	12	6years and 5 months - to 13years and 5 months	10M-2F	ID is not mentioned / 2 participants with ADHD + PPDs, 10 with ADHD + DCD	not specified
De Luca et al.	2019	case	1	16years	1M	ID	severe
Kreibich, Chen, & Reichle	2015	case	1	4 years and 3 months	1M	ID	mild to moderate
Pasiali, LaGasse, & Penn	2014	case	9	13-20years	4M-5F	ID	severe to minimal
Rose, Trembath, & Bloomberg	2016	case	3	3 years and 2 months to 4years and 1 month	3M	not mentioned	not specified
Steiner et al.	2014	case	10	7-11years	9M-1F	Without ID/Additional co-morbid psychiatric diagnosis or a developmental delay	high functioning

Note. M = male; F = Female; ID = intellectual disability; PDD-NOS = Pervasive Developmental Disorders Not Otherwise Specified; ADHD = Attention-Deficit/ Hyperactive Disorder; DCD = Developmental Coordination Disorder; ASD = Autism Spectrum Disorde

Study design and intervention characteristics.

As depicted in Table 2, five out of the thirteen studies were group studies employing randomized control trials (RCTs) with experimental and control groups of participants matched at baseline, while in three of them control groups were active (Chan et al., 2013; De Vries et al., 2015; Spaniol et al., 2017). The rest eight studies employed single-case design, where the participants served as their own control. Additionally, different types of single-case designs were applied by the researchers such as multiple baseline (Cosper et al., 2009; Rose, Trembath, Bloomberg, 2016) or multiple-probe design across tasks (Kreibich, Chen, & Reichle, 2015).In respect of the core attention skills targeted for intervention, seven studies out of the thirteen addressed only one core attention skill, while in another three studies, a pair of attention skills was treated, either sustained attention and inhibitory control, namely attention control (Cosper et al., 2009; Steiner et al., 2014) or sustained attention and selective spatial attention (De Luca et al., 2019). Finally, three RCT studies treated all three core attention skills, namely sustained attention, selective spatial attention and attention control (Pasiali, LaGasse, & Penn, 2014; Powell et al., 2016; Spaniol et al., 2017).

A diversity of intervention approaches was applied to improve attention. Participants in six of the thirteen studies underwent a computerized attention training (Chukoskie, Westerfield, & Townsend, 2017; Cosper et al., 2009; De Vries et al., 2015; Powell et al., 2016; Spaniol et al., 2017; Steiner et al., 2014).

Specifically, Chukoskie, Westerfield, and Townsend (2017) used gaze-contingent video games for low-cost in-home training, designed with principles to train fixation, speed and accuracy of eye movements and control of visuo-spatial attention. As the gamers play longer and gain competency, all games increase in difficulty, speed and active field of view. The Interactive Metronome was used by Cosper et al. (2009). It is a noninvasive, PC-based technique developed in 1992, that requires children to practice the timing and rhythmicity of various movement combinations of the hands and feet in response to auditory cues (Shaffer et al., 2001). De Vries et al., 2015 used Braingame Brian, a computerized Executive Function (EF) training with game-elements. A training battery consisted of four different training tasks (*Butterfly, FlyMe, Stars* and *Suspects*) targeting a combination of interference resolution, inhibition, visual search, online goal maintenance and task-switching was used by Powell et al. (2016).

Spaniol et al. (2017) used three of the training tasks included in the Computerized Progressive Attentional Training (CPAT; Shalev et al., 2007). The first of the three training tasks is The Computerized Continuous Performance Task (CCPT), targeting sustained attention. The second task, The Conjunctive Search Task (CST) targets selective - spatial attention and the third one, the Shift Stroop-like Task is designed to improve the function of executive attention and cognitive control. Finally, Steiner et al. (2014) used a commercially available neurofeedback system designed to train attention (Play Attention ®).

In three out of the thirteen studies, the intervention program involved physical activity. More specifically a mind-body exercise was used to train attention in two studies (Chan et al., 2011; Chan et al., 2013) and basketball skill learning (Tse et al., 2019). The remaining four studies out of the total trained attention through: a) a combined approach using virtual reality and cognitive behavioral therapy (De Luca et al., 2019), b) engagement tasks (Kreibich, Chen, & Reichle, 2015), c) a group music therapy (Pasiali, LaGasse, & Penn, 2014) and d) Key Word Sign (Rose, Trembath, Bloomberg, 2016) (see Table 2).

In reference to the intervention setting/nature and the person who delivered the intervention, five of the studies took place at schools, during lesson times (Kreibich, Chen, & Reichle, 2015; Pasiali, LaGasse, & Penn, 2014; Powell et al., 2016; Spaniol et al., 2017; Tse et al., 2019), with three of them implemented in an individual context and the intervention delivered by the researchers or a practitioner (Kreibich, Chen, & Reichle, 2015; Powell et al., 2016; Spaniol et al., 2017). The other two school-based interventions were delivered in groups and one of them was again delivered by a researcher (Pasiali, LaGasse, & Penn, 2014), whereas the second one involved trained school staff (Tse et al., 2019). In another three studies, interventions were delivered individually by practitioners or the researchers in research settings (De Luca et al., 2019; Rose, Trembath & Bloomberg, 2016; Steiner et al., 2014). Another two interventions took place at the participant's home (Chukoskie, Westerfield, & Townsend, 2017; De Vries et al., 2015) with the second one involving the parents, after appropriate training. Interventions taking place in a clinic or research setting with a combined practice at home were implemented in two studies (Chan et al., 2011; Chan et al., 2013), though one was delivered in individual sessions and the other one in groups, with regard to research setting. Finally, one intervention took place in a clinic setting and was delivered by a practitioner in individual sessions (Cosper et al., 2009).

In terms of timeline, intervention was delivered from a minimum of one month to a maximum of eight months. The frequency of the sessions and their time length varied from a minimum of 30 to 45 minutes twice a week for an average of ten weeks to 1 hour/ 5 days a week for 6 weeks or 1 hour/once a week for 15 weeks (see Table 2).

Table 2. Study design, type of core attention, type of intervention, intervention setting and nature, duration

Author	Year	Group/Case Study	Research design	Type of Control group	Groups matched at baseline	Type of core Attention	Type of Intervention	Intervention setting	Intervention nature(one-to-one/groups) /Interventionist	Duration/Overall time/number of sessions
Chan et al.	2013	group	RCT	Active control group	√	IC, flexibility	Chan-based mind-body exercise, Nei Yang Gong	Home/ research setting	Groups /practitioner parents	1 month/twice per week/1 hour session
De Vries et al.	2015	group	RCT	Active control group	√	Flexibility, IC	Computerized; "Braingame Brian" http://en.gamingandtraining.nl/description-braingame-brian/	Home	One to one/parents	6 weeks (5 weeks and one spare)/25 sessions/ 30 min session (15min cognitive flexibility, 15min inhibition)
Powell et al.	2016	group	RCT	Active control group	√	VSA, SSA, AC	Computerized; gaze-contingent attention training games	School	One -to-one/ researcher	twice per week, until the child had completed 120min.
Spaniol et al.	2017	group	RCT	Active control group	√	SA, SSA, AC	Computerized Progressive Attentional Training; (CPAT); http://attention.tau.ac.il/cpat/	School	One -to-one /researcher	8 weeks/13 sessions (12–14) of approximately 45 minutes, twice a week
Tse et al.	2019	group	RCT	Passive control group	√	IC	Basketball skill learning	School	Groups/school staff	12 weeks /24 sessions/two sessions per week/45min session

Chan et al.	2011	case	SCD	–	–	IC	Dejian Mind -body exercise	Home /clinic	one-to-one/researcher / parents	8 months/15-minute weekly sessions first month/15 min monthly sessions the rest 7 months
Chukoskie, Westerfield, & Townsend	2017	case	SCD	–	–	SSA	Computerized; Gaze- contingent video games https://medschool.ucsd.edu	Home	One-to -one/parents	8 weeks/30 min session/5 times per week
Cosper et al.	2009	case	SCD/ Multiple baseline	–	–	SA, MIC	Computerized; Interactive Metronome https://www.interactivemetronome.com/	Clinic	One to one/practitioner	15 weeks/1-h session/once a week
De Luca et al.	2019	case	Case study	–	–	SSA, SA	Combined approach using VR and CBT	Research setting	One to one/practitioner	16 weeks/24 CBT and 24 CBT plus VR, respectively/ three times a week/ 40 min session.
Kreibich, Chen, & Reichle	2015	case	SCD/Multiple-probe design across tasks	–	–	SA	Engagement tasks	School	One to one/ practitioner	14weeks/3-hr sessions/one to three times per week
Pasiali, LaGasse, & Penn	2014	case	SCD	–	–	SA, SSA, AC/switching	Group Music Therapy	School	Groups/researcher	eight 45-min sessions over a period of 6 weeks
Rose, Trembath, & Bloomberg	2016	case	SCD/ multiple baseline	–	–	VA	Key Word Sign (Makaton)	Research setting	One -to-one/ practitioner	12 weeks/45 min sessions, 3 times per week

Steiner et al.	2014	case	SCD	–	–	SA, AC	Computerized; NFB system Play Attention https://www.playattention.com/	Research setting	One -to-one or in pairs/ researcher	6 weeks-Monday through Friday/1-h

Note. SCD = Single case design; RCT = Randomized Control trial; IC = Inhibitory Control, SA = Sustained Attention, AC = Attention Control**;** IC= Inhibitory Control; NFB = Neurofeedback

Outcome measures, Transfer effects, Follow-up measures and Feasibility data

As depicted in Table 3, eight of the selected intervention studies in the current review accommodated core attention skills as needed within the context of broader intervention targets. The remaining five studies targeted exclusively attention (Chukoskie, Westerfield, & Townsend, 2017; De Vries et al., 2015; Pasiali, LaGasse, & Penn, 2014; Powell et al., 2016; Spaniol et al., 2017). Both objective and subjective measures, with the latter being mostly behavioral rating scales on autism, were used in seven of them (Chan et al., 2011; Chan et al., 2013; De Luca et al., 2019; De Vries et al., 2015; Pasiali, LaGasse, & Penn, 2014; Spaniol et al., 2017; Steiner et al., 2014). The rest used only objective measures in pretest and posttest assessments of attention (Chukoskie, Westerfield, & Townsend, 2017; Cosper et al., 2009; Kreibich, Chen, & Reichle, 2015; Powell et al., 2016; Rose, Trembath, & Bloomberg, 2016; Tse et al., 2019).

Besides, improvement on attention was documented in eleven of the studies. One study reported no improvement on sustained attention and motor inhibitory control (Cosper et al., 2009) and another one reported improvement only in one of the participants (Rose, Trembath, & Bloomberg, 2016).

In respect of transfer effects, near transfer effects on non-trained tasks were documented in all 13 studies. Far transfer effects were documented only in six of them and were all related to autistic behaviours, but one. Reduction of emotional outbursts (Chan et al., 2011), reduction of temper outbursts and obsessive behaviours (Chan et al., 2013) significant reduction of ideomotor stereotypes and improvement of parent’s general distress (De Luca et al., 2019), reduction of ADHD-like behavior (De Vries et al., 2015), positive change on the DSM-IV and the Social/ Communication subscales of the Autism Spectrum Rating Scale (ASRS) (Steiner et al., 2014) and sleep quality (Tse et al., 2019) were reported. Interestingly, only one study reported a positive impact of core functions of attention training on the academic performance of students with ASD (Spaniol et al., 2017) (see Table 3).

Follow-up measures were taken in two of the studies for the long-term effects of their interventions to be examined (Chan et al., 2011; De Vries et al., 2015).

In respect of the drop-out rates, the majority of the studies (10) reported zero attrition, while the remaining three reported 13% (Chan et al., 2013), 25% (Chukoskie, Westerfield, & Townsend, 2017) and 30% (De Vries et al., 2015) respectively.

Finally, based on the operationalization of the concepts regarding implementation fidelity (Dane & Schneider, 1998; Roberts et al., 2017), four of the selected studies in the current review assessed fidelity of the intervention implementation including measures regarding how and whether the implementation agent was faithful to the guidelines of the intervention (adherence to intended protocol) as well as measures on the quality of delivery and participant's responsiveness (Chukoskie, Westerfield & Townsend, 2017; Kreibich, Chen, & Reichle, 2015; Powell et al., 2016; Steiner et al., 2014).

The other nine studies provided a detailed description of the training protocol and details on how frequent and for how long the intervention took place. Additionally, a description of the presumed (theoretical) theory of change, related to a general theory or theories which justify the intervention activities and a presentation of the critical components, essential for the effectivity of the intervention were also provided.

Table 3. Outcome measures, Transfer effects and Follow-up measures.

Author	Year	Group/ case study	Outcome measures	Type of measures (Subjective or Objective)	Improvement documented	Near transfer effects	Far transfer effects	Follow-up measures
Chan et al.	2013	group	TOLDX; CCTT; FPT; ATEC; Event-related EEG assessment during a Go/No-Go task	both	√	self-control, IC and flexibility	reduction of temper, outbursts and obsessive behaviours	–
De Vries et al.	2015	group	Corsi-BTT; Gender-emotion switch task; N-back task; Number-gnome switch task; Stop-task; SART; DBDRS; BRIEF; CSBQ; PedsQL	both	√	WM, a trend in flexibility	ADHD-like behavior	√
Powell et al.	2016	group	VSA; Anticipatory saccades; Attentional disengagement latencies/saccadic RT	objective	√	VSA and trends of training effect on disengagement of visual attention	–	–
Spaniol et al.	2017	group	CPM; CARS; tests in maths, reading comprehension, passage copying, semi-structured Interviews	both	√	non-verbal cognition and attention	academic skills	–
Tse et al.	2019	group	Sleep quality (measured with an actigraphy accelerometer); GNG task; CBTT; FDS; BDS	objective	√	IC	sleep quality	–

Note. TOLDX = The Tower of London Test – Drexel Version (Culbertson & Zillmer, 2005); CCTT= Children's Color Trails Test (D'Elia et al., 1996); FPT = Five Point Test (Regard, Strauss & Knapp, 1982); ATEC = Autism Treatment Evaluation Checklist (Rimland & Edelson, 1999) ; Corsi-BTT = Corsi block tapping task (Corsi, 1972); SART = Sustained attention response task (Robertson et al., 1997); DBDRS = Disruptive Behavior Disorders Rating Scale (Pelham et al., 1992); BRIEF = Behaviour Rating Inventory of Executive Function (Gioia et al., 2000); CSBQ = Children's Social Behavior Questionnaire (Hartman et al., 2006); PedsQL= Pediatric Quality of Life Inventory (Bastiaansen et al., 2004); CPM = Computerized Progressive Matrices (Raven et al. 2008); CARS = Childhood Autism Rating Scale (Schopler et al. 1980, 1988); GNG = Go/No-Go; CBTT = Corsi block tapping task (Corsi, 1972); FDS; Forward Digit Span test (Thorndike, Hagen, & Sattler, 1986); BDS; Backward Digit Span test (Thorndike, Hagen, & Sattler, 1986); IC = Inhibitory Control; WM = Working Memory; VSA = Visual Sustained Attention; RT = Reaction Time; ADHD = Attention-Deficit/Hyperactivity disorder

Chan et al.	2011	case	HKLLT; CCTT; BRIEF	both	√	IC and flexibility	reduction of emotional outbursts	√
Chukoskie, Westerfield, & Townsend	2017	case	Spatial Attention Task(E-Task); Gap-Overlap Saccade Task	objective	√	SSA and eye movement control	–	–
Cosper et al.	2009	case	Bruininks–Oseretsky Test of Motor Proficiency-Short Form; GDS (Model III-R)	objective	No improvement on SA and MIC	reaction times	–	–
De Luca et al.	2019	case	RPM; MTCM; VMI; GARS; QSG	both	√	attention processes and visuo-spatial skills	reduction of ideomotor stereotypes and improvement of parent's general distress	–
Kreibich, Chen, & Reichle	2015	case	Engagement duration; number of break requests during engagement tasks	objective	√	learning to request breaks and engagement duration	–	–
Pasiali, LaGasse, & Penn	2014	case	TEA-Ch; CARS2-HF	both	√	SSA and AC/switching.	–	–
Rose, Trembath, & Bloomberg	2016	case	VA was measured as occasions on which the child looked in the direction of signing space, sign production observed during baseline	objective	improvement mentioned in one of the participants	VA	–	–
Steiner et al.	2014	case	PERMP; CPT; CRS 3-P; ASRS; CARS	both	√	TOT percent during academic work, RI	DSM-IV and the Social/ Communication subscales of the ASRS	–

Note. HKLLT= Hong Kong List Learning Test (Chan, 2006); CCTT= Children's Color Trails Test (D'Elia et al., 1996); BRIEF = Behaviour Rating Inventory of Executive Function (Gioia et al., 2000); GDS (Model III-R) = Gordon Diagnostic System (Gordon, 1979); RPM = Raven Progressive Matrices (Raven, Raven, & Court, 1998); MTCM = The Modified Little Bell Test (Biancardi & Stoppa, 1997); VMI = Developmental Test of Visual-Motor Integration (Beery, Buktenica, & Beery, 2004); GARS = Gilliam Autism Rating Scale (Gilliam, 2006); QSG = Questionnaire on Parental Distress (Menazza, Bacci, & Vio, 2010);TEA-Ch = Test of Everyday Attention for Children (Manly et al., 1999); CARS2-HF = High Functioning Version of the Childhood Autism Rating Scale (Schopler et al., 2010); PERMP = Permanent Product Measure of Performance (Wigal & Wigal, 2006); CPT = Continuous Performance Test; CRS 3-P = Conners Rating Scale-Parent (Conners et al., 1998); ASRS = Autism Spectrum Rating Scale (Goldstein & Naglieri, 2011); CARS = Childhood Autism Rating Scale (Schopler et al. 1980, 1988); SA = Sustained Attention; MIC = Motor Inhibitory Control; IC = Inhibitory Control; SSA = Selective Spatial Attention; AC = Attention Control; VA = Visual Attention; TOT= Time on Task; ; RI = Response Inhibition;

Effect size

We recorded effect size or alternative statistical tests evaluating the improvement of core functions of attention in the 13 selected studies of the current review. In addition to Cohen’s d and Tau-U, there were several different types of effect sizes recorded from original study findings, including Z-scores, standardized mean difference, non-overlapping data (PND), Pearson r, Reliable Change Indices analysis (RCI) and partial eta squared, ranging from small to large training effects. Due to this reason, the range of effects and means are not described in text, but can be found in Table 4.

Table 4. Effect size (or alternative statistical test)

Author	Year	Near transfer effects	Far transfer effects	Effect size
Chan et al.	2011	inhibitory control and flexibility	reduction of emotional outbursts	● Inhibitory control: reduction in Intrusion score from 9 to 0, as assessed by the HKLLT ● Flexibility: improved from “severely impaired” to “low average to average” as measured by the Intrusion score (non-target word) and False Alarm (new words misidentified as learned words) on the HKLLT and set-shifting error in CCTT ● Mother’s rating on using the BRIEF: improved from “moderately impaired” to “borderline in BRI (from 1st to 13th Percentile rank) and low average in GEC (from 1st to 20th Percentile rank) at post-8- month DMBI
Chan et al.	2013	self-control, inhibitory control and flexibility	reduction of temper outbursts and obsessive behaviours	(see below)

Outcome Measure	Experimental group effect size	Control group effect size	Group difference effect size
TOLDX: reduction of frequency rule violation			0.84
TOLDX: increased average initial time in attempting the questions	0.86	0.14	
Reduction in impulsivity	0.77		
CCTT-T2 reduction in completion time	0.83	0.41.	0.55
FPT	0.80	0.63	
ATEC sociability scale	0.68	0.58	
ATEC sensory / cognitive awareness	0.49		
ATEC health/physical behaviour	0.66		
ATEC Temper outburst scale			0.86
ATEC Obsession scale			0.69

Note. HKLLT = Hong Kong List Learning Test (Chan, 2006); CCTT- T2 = Children’s Color Trails Test (Williams, et al., 1995); BRIEF = Behaviour Rating Inventory of Executive Function (Gioia et al., 2000); BRI = Behavioral Regulation; CEG = General Executive Composite; DMBI = Dejian Mind-Body Intervention; TOLDX = The Tower of London Test – Drexel Version (Culbertson & Zillmer, 2005); FPT = Five Point Test (Regard, Strauss & Knapp, 1982); ATEC = Autism Treatment Evaluation Checklist (Rimland & Edelson, 1999)

Table 4. Continued

Chukoskie, Westerfield, & Townsend	2017	selective spatial attention and eye movement control	–	● Spatial attention measure (speed of orienting): improvement range from -0.5 to 20 SEM* ● Reduced time to disengage attention after 4 weeks of training: improvement range from1.5 to 11 SEM* ● Duration of gaze fixation: improvement range from 1.7 to 11 SEM* ● Saccade latency: improvement range from -4 to 3.5 SEM* ● Saccade accuracy: improvement range from 26 to 15.5 SEM* *Based on means and variance from age-matched typical children, SEM (standard error of the mean) ≥ 2
Cosper et al.	2009	reaction times	–	● Significant improvements in complex visual choice reaction time on the CPT ($t = 2.37$, d.f. = 11, $p = 0.04$)
De Luca et al.	2019	attention processes and visuo-spatial skills	ideomotor stereotypes and parent's general distress	● MTCM: Rapidity score 2.1; Accuracy scores 3.2* ● VMI: 3.5 ● GARS stereotyped behaviors: 2.8 ● GARS sum total subtests: 2.1; GARS Quotient autism 2.3 ● QSG Emotional load: 2.1 > 1.96 (only for the combined approach of VR (BTS-Nirvana System) and CBT) *Rci > 1.96
De Vries et al.	2015	working memory, a trend on flexibility	ADHD-like behavior	● Corsi-BTT: F (4,164) 2.6* η^2p = .06 (Time*Intervention) ● Flexibility: (F (2, 117) = 4.6, p = .01, η^2p = 0.7(Time*Intervention) ● DBDRS-ADHD: F (2.168) 2.5* η^2p = .06 (Time*Intervention)
Kreibich, Chen, & Reichle	2015	learning to request breaks and engagement duration	–	● The PND of appropriate break requests across the entire intervention, as compared with baseline, were 83.3% for Task Set* 1, 86.7% for Task Set 2*, and 100% for Task Sets 3 and 4*. The PND was not calculated for engagement duration *Effect size was calculated by using the percentage of nonoverlapping data (PND)
Pasiali, LaGasse, & Penn	2014	selective spatial attention and attentional control/switching	–	● Selective Attention: Sky Search t = 2.66, d.f. = 8, p=0.029* ● Map Mission t = -4.05, d.f.= 8, p= 0.004* ● Attentional Control/Switching: Creature Counting t (8) =-2.774, d.f. = 8, p = 0.024* ● Opposite Worlds t = 2.46, d.f.= 8, p = 0.039*
Powell et al.	2016	visual sustained attention and trend on disengagement of visual attention	–	● Visual sustained attention: F (16) = 5.2, p = 0.019. ● Disengagement of visual attention: F (15) = 3.00, p = 0.075

Note. CPT = Continuous Performance Test; RCI = Reliable Changes Index; MTCM = The Modified Little Bell Test (Biancardi & Stoppa, 1997); VMI = Developmental Test of Visual-Motor Integration (Beery, Buktenica, & Beery, 2004); GARS = Gilliam Autism Rating Scale (James & Gilliam, 2006); OSG = Questionnaire on Parental Distress (Menazza, Bacci, & Vio, 2010); VR = Virtual Reality; CBT = Cognitive Behavioral Therapy; Corsi-BTT = Corsi block tapping task (Corsi, 1972); DBDRS = Disruptive Behavior Disorders Rating Scale (Pelham et al., 1992)

Table 4. Continued

Rose, Trembath, & Bloomberg	2016	visual attention	–	• Significant increase in visual attention of one of the three participants: Tau-U = 0.852, p = 0.034
Spaniol et al.	2017	non-verbal cognition and attention	academic skills	• CPM: Cohen’s d = −1.32 • Maths: Cohen’s d = − 1.60 • Reading Comprehension: Cohen’s d =−1.53 • Copying: Cohen’s d= −1.6 • Semi-structured interviews with the teaching staff: more reports of improvements in attention within the CPAT group (87.5%) in comparison to the CG group (33.3%; χ^2 = 4.38, df = 1, p = 0.036; Fisher’s exact test p = 0.091) • Semi-structured interviews with the teaching staff: more reports of academic improvement in CPAT group (100%) in comparison to children in the CG group (33.3%; χ^2 = 7.47, df = 1, p = 0.006; Fisher’s exact test p = 0.015)
Steiner et al.	2014	Time on Task during academic work, response inhibition	DSM-IV and the Social/ Communication subscales of the ASRS	• PERMP: z = 2.38, p= 0.02* • Full Scale Response Control Quotient: z=2.08, p= 0.04* • ASRS - DSM-IV: z= -2.45, p=0.01* • ASRS - Social/Communication z =-2.20, p = 0.03*
Tse et al.	2019	inhibition	sleep quality	• SE and WASO: Cohen’s d ranged from 0.66 to 0.77 • SD: Cohen’s d ranged from 0.16 to 0.29 • FA errors group difference: t = −3.43, d.f. = 38, p = 0.001

Note. CPM = Computerized Progressive Matrices (Raven et al., 2008); CARS = Childhood Autism Rating Scale (Schopler et al., 1980, 1988); CPAT = Computerized Progressive Attentional Training (Shalev, Tsal, & Mevorach, 2007); TOT = Time on Task; PERMP = Permanent Product Measure of Performance (Wigal & Wigal, 2006); ASRS = Autism Spectrum Rating Scale (Goldstein & Naglieri, 2011); SE = Sleep efficiency; WASO = Wake after sleep onset; SD = Sleep duration; FA= False alarm

Synthesizing results across studies for computerized attention training

This review has included both group study designs (i.e. RCTs) and single subject experimental designs. Reichow, Volkmar and Cicchetti designed a method to assess the strength of evidence specifically for studies focused on autistic children that can be applied to both methods together (Reichow et al, 2008, Cicchetti, 2011). Research has shown that this evaluative method produced reliable and valid results (Cicchetti, 2011; Gevarter et al, 2016; Reichow & Volkmar, 2010), and has been used in syntheses of best practices related to video-based mathematics training (Hughes & Yakuboka, 2019), peer-mediated social interaction (Watkins et al, 2015) and school-based peer-related social competence (Whalon et al, 2015).

Hence, we regarded this evaluative method as an appropriate tool to attempt a synthesis of the interventions on core functions of attention training for children and adolescents with ASD identified in the present study. Of the thirteen reports, two (15,3%) reports received a strong rigor rating and seven studies received an adequate rigor rating. Five studies out of the nine receiving strong and adequate rigor ratings investigated the feasibility and efficacy of computerized attention training programs for children and adolescents with ASD and were synthesized to examine the status of computerized attention training as an Evidence - Based Practice (EBP). The rest four studies, although they received an adequate rigor raring couldn't be synthesized due to different practices. (see Table 5).

Table 5. EBP status of computerized attention training for children and adolescents with ASD

Study	**Research method**	**Rigor**	**Successful N**
De Vries et al., 2015	GROUP	Strong	0
Powell et al., 2016	GROUP	Adequate	9
Spaniol et al., 2017	GROUP	Adequate	8
Chukoskie, Westerfield, & Townsend, 2017	SSED	Adequate	5
Steiner et al., 2014	SSED	Adequate	10

Number of group studies with strong rigor ratings 1 = $GROUP_S$

Number of group studies with adequate rigor ratings 2 = $GROUP_A$

Number of participants from SSED studies with strong rigor ratings 0 = $SSED_S$

Number of participants from SSED studies with adequate rigor ratings 15 = $SSED_A$

Formula for Determining EBP Status

$$(GROUP_S * 30) + (GROUP_A * 15) + (SSED_S * 4) + (SSED_A * 2) = Z$$

$$(1 * 30) + (2 * 17) + (0 * 4) + (2 * 15) = 94$$

$$Z=94$$

In summing the values, computerized interventions for increasing attention in children and adolescents with ASD amassed 94 points, which exceeds the criterion for an established EBP (Table 6).

Table 6. Criterion for an established EBP

Points (Z)	0 10 20 30	31 40 50 59	60+
EBP Status	Not an EBP	Probable EBP	Established EBP

Discussion

We reviewed the literature to identify published research focused on interventions targeting core attention functions in individuals with ASD, since impairments to attention have often been considered to be associated with the disorder (Keehn et al., 2013). Besides, attention is highly subject to improvement with training in typically developing children (MacSween, 2017; Sarzyńska, et al., 2017) and children with ADHD (Bikic et al., 2018; Tucha et al., 2011). Our systematic search revealed a plethora of interventions on joint attention and highlighted the limited intervention literature on core attention functions. An attempt to categorize the limited evidence-based training programs on core attentions skills led to the formulation of two distinct categories: a) computer-based training programs, including six studies and b) involving physical activity, including three studies. The rest four studies trained attention through: a) combined approach using virtual reality and cognitive behavioral therapy b) engagement tasks), c) group music therapy and d) Key Word Sign. All the studies, but one, reported improvement on the targeted core attention skills.

Directions for future research

Impairments to attention have often been considered to be associated with ASD (Mayes & Calhoun, 2007). Indeed, recent research into the emergence of the ASD phenotype suggests that differences in aspects of attention appear very early in ASD symptomatology (Keehn et al. 2013). Additionally, difficulties have been reported in aspects of volitional attention control not only in social but also in non-social situations (Benson et al., 2012; Kourkoulou et al., 2013).

In fact, recent research indicates that difficulties which are specific to social orienting are not generally detectable at very early stages of development (Chawarska et al., 2013; Constantino et al., 2017; Jones et al., 2014). On the contrary, impairments in domain-general aspects of development, including aspects of non-social attention, have been noted very early in infants who later received a diagnosis of ASD. For example, Elison et al. (2013) found that infants, who later developed ASD, were slower to disengage attention at the age of 7 months and Wass et al. (2015) found differences in micro-temporal eye movement patterns in 6-month-old infants who later developed ASD. In particular, these attention deficits may affect early social development particularly by disrupting joint attention (Schietecatte et al., 2012; Mundy et al, 2007).

Nevertheless, the vast majority of interventions studies emerged from our literature search targeted joint attention skills compared to a limited number of interventions on core functions of attention. Researchers seem to rely more on social/emotional stimuli vs. neutral stimuli (or both), when they investigate attention in ASD (Wang et al (2015). This comes as no surprise, given that symptoms of attention impairments appear to be exacerbated in social contexts (Osterling et al., 2002) and as a result joint attention becomes a more distinguishing feature of autism (Patten & Watson, 2010).

The majority of the studies used a small sample size ranging from 1- 17 participants, apart from three (Chan et al., 2013; De Vries et al., 2015; Tse et al., 2019). Future researchers should try to include larger samples, which will allow for results to be generalized to the larger population of children with ASD.

In respect of the study design, only five were RCTs, which are the most stringent way of determining whether a cause-effect relation exists between the intervention and the outcome (Kendall, 2003). Thus, future researchers should conduct more RCTs, due to their strong confidence and robustness in producing data with regard to the effectivity of the intervention.

Additionally, a diversity of intervention approaches and timeline exposure does not exactly provide clarity and consistency in the field of core attention training. Besides, eight of the studies in the current review accommodated attention as needed within the context of broader treatment targets, therefore, treatment intensity is difficult to ascertain. Consequently, future training techniques should focus solely on core attention skills, if the effectiveness is to be evaluated.

Most importantly, intervention protocols have been published in advance in only four studies (Cosper et al., 2009; De Vries et al., 2015; Spaniol et al., 2017; Steiner et al., 2014). Future similar studies should consider publishing the protocol first in order to strengthen their validity and reliability.

Another point under consideration is the absence of follow-up measures. Indeed, only two studies reported such measures (Chan et al., 2011; De Vries et al., 2015), thus increasing the overall effectiveness of their research effort on attention training.

In respect of transfer effects, near transfer effects on non-trained tasks were documented in all 13 studies. Far transfer effects were documented only in 6 of them and were all related to autistic behaviours, but one (Spaniol et al., 2017) which reported a positive impact of a school-based attention training on the academic performance of students with ASD.

Admittedly, recent research (Erickson et al., 2015) highlights the importance of selective and sustained attention in supporting learning in a classroom setting since early infancy. In particular, selective attention has been found to play an important role in the development of both literacy and numeracy (Stevens & Bavelier, 2012). Furthermore, Stern and Shalev (2013) found that poor performance in reading and reading comprehension was related to difficulties in sustained attention. Yet, another function of attention-executive attention-was linked to children's ability in maths (Bull & Scerif, 2001; May et al., 2013). Similarly, in a follow-up study, May et al. (2015) also found that attention switching correlated with both maths and reading performance in ASD. Thus, attentional atypicalities seen in the performance of ASD individuals might not only have implications for the severity of ASD symptoms (Keehn et al., 2013), but also for academic skills in school settings. Consequently, future researchers should investigate the effects of core attention training on the improvement of academic skills in ASD, aiming to develop intervention programs for schools and promote successful learning for children with ASD in a school environment (Kasari & Smith 2013; Parsons et al., 2013). Besides, training effects are generally found to be stronger, when training is applied at early stages of development (Wass et al., 2012).

In terms of feasibility, the majority of the studies reported zero attrition. As for the fidelity of implementation, based on the operationalization of the concepts regarding implementation fidelity (Dane & Schneider, 1998; Roberts et al., 2017), we found only three studies in the current review, which measured fidelity. Future intervention studies on core functions of attention should measure whether an intervention has been implemented with fidelity, so as researchers and practitioners gain a better understanding of how and why an intervention works, and the extent to which outcomes can be improved.

Limitations

This review is not without limitations. One limitation is that only English peer-reviewed articles, reviews, meta-analyses and book chapters were included and it is possible that other research papers may have been published in other languages. Moreover, a systematic search in other databases apart from the 3 used, might have yielded additional studies. Given the nature of the results found by this systematic review, in which a high percentage of the papers included were related to computerized attention training programmes, including technological databases such as ACM or IEEE would have produced more results. However, given the nature of technological journals, where technology design issues are more common than empirical studies, the impact of having included those databases would have limited effect on the results of this review.

A second limitation is that we did not include executive function(s) as a term in our systematic search. Indeed, it was purposefully omitted from the final stage of the literature search as its inclusion in previous searches has shown it was too broad and resulted in a large number of irrelevant publications. Given the high volume of papers the researchers had to review it was decided that a narrower search would be more appropriate.

Regarding the results of the evaluation with respect to evidence-based practices, they should be interpreted with attentiveness, since the inclusion criteria narrowed the scope of this review. Thus, our results of the EBP status of computerized attention training programs included in this review should be used as a starting point for further evaluation of similar practices close to meeting EBP criteria.

Finally, we recorded the effect size or alternative statistical tests with regard to the improvement of core attention skills, a meta-analysis of the results was not conducted, due to the limited RCTs included in the current review.

Conclusion

At present, a paucity of research on interventions targeting core skills of attention leaves us with individual studies that suggest promising outcomes but a critical need for replication, extension, and controlled studies of the factors that moderate treatment outcome.

We conclude that core functions of attention training can be effective, but that there are factors that must be considered, when evaluating the effects of this training. We propose that future research should investigate what training regimens and what training conditions result in the best transfer effects, while considering the heterogeneous identity of ASD, which may result in individual differences in attention training performance of individuals with ASD.

References

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders.* (5th edn). Arlington, VA: American Psychiatric Publishing.

Bastiaansen, D., Koot, H. M., Bongers, I. L., Varni, J. W., & Verhulst, F. C. (2004). Measuring quality of life in children referred for psychiatric problems: Psychometric properties of the PedsQL TM 4.0 generic core scales. *Quality of Life Research, 13*(2), 489–495.

Beery, K.E., Buktenica, N. A., & Beery, N. A. (2004). *The Beery-Buktenica Developmental Test of Visual Motor Integration.* Minneapolis, MN: NCS Pearson.

Benson, V., Castelhano, M. S., Au-Yeung, S. K., & Rayner, K. (2012). Eye movements reveal no immediate “WOW” (“which one's weird”) effect in autism spectrum disorder. *Quarterly Journal of Experimental Psychology, 65*(6), 1139–1150.

Biancardi, A., & Stoppa, E. (1997). Il Test delle Campanelle modificato: una proposta per lo studio dell' attenzione in eta evolutiva. *Psichiatria Infanzia Adolescenza, 64*(1), 73–84.

Bikic, A., Leckman, J. F., Christensen, T. Ø., Bilenberg, N., & Dalsgaard, S. (2018). Attention and executive functions computer training for attention-deficit/hyperactivity disorder (ADHD): results from a randomized, controlled trial. *European Child & Adolescent Psychiatry, 27*(12), 1563–1574.

Bruininks, R.H. (1978). *Bruininks–Oseretsky Test of Motor Proficiency. Examiners manual.* Circle Pines, MN: American Guidance Service, Inc.

Bull, R., & Scerif, G. (2001). Executive functioning as a predictor of children’s mathematics ability: Inhibition, switching, and working memory. *Developmental Neuropsychology, 19*(3), 273–293.

Chan, A. S. (2006). *Hong Kong List Learning Test.* Hong Kong: The Chinese University of Hong Kong, Department of Psychology.

Chan, A. S., Sze, S. L., Cheung, M. C., Han, Y. M. Y., Leung, W. W., & Shi, D. (2011). Dejian mind-body intervention improves the cognitive functions of a child with autism. *Evidence-based Complementary and Alternative Medicine, 2011*, 549254.

Chan, A. S., Sze, S. L., Siu, N. Y., Lau, E. M., & Cheung, M. C. (2013). A Chinese mind-body exercise improves self-control of children with autism: a randomized controlled trial. *PLoS One, 8*(7), e68184.

Chawarska, K., Macari, S., & Shic, F. (2013). Decreased spontaneous attention to social scenes in 6-month-old infants later diagnosed with autism spectrum disorders. *Biological Psychiatry, 74*(3), 195-203.

Chien, Y. L., Gau, S. S., Shang, C. Y., Chiu, Y. N., Tsai, W. C., & Wu, Y. Y. (2015). Visual memory and sustained attention impairment in youths with autism spectrum disorders. *Psychological Medicine, 45*(11), 2263–2273.

Chukoskie, L., Westerfield, M., & Townsend, J. (2018). A novel approach to training attention and gaze in ASD: A feasibility and efficacy pilot study. *Developmental Neurobiology, 78*(5), 546–554.

Cicchetti, D. V. (2011). On the reliability and accuracy of the evaluative method for identifying evidence-based practices in autism. In B. Reichow, P. Doehring, D. V. Cicchetti, & F.R. Volkmar (Eds.), Evidence-based practices and treatments for children with autism (pp. 41–51). New York, NY: Springer.

Colombo, J., & Cheatham, C. L. (2006). The emergence and basis of endogenous attention in infancy and early childhood. In R. V. Kail (Ed.), *Advances in Child Development and Behaviour* (Vol. 34, pp. 283–322). Amsterdam: Elsevier.

Conners, C., Sitarenios, G., Parker, J. D. A., & Epstein, J. N. (1998). The revised Conners' parent rating scale (CPRS-R): Factor structure, reliability, and criterion validity. *Journal of Abnormal Child Psychology, 26*(4), 257–268.

Constantino, J. N., Kennon-McGill, S., Weichselbaum, C., Marrus, N., Haider, A., Glowinski, A. L., ... & Jones, W. (2017). Infant viewing of social scenes is under genetic control and is atypical in autism. *Nature, 547*(7663), 340-344.

Corsi, P. M. (1972). Human memory and the medial temporal region of the brain (University Microfilms No. AA105-77717) [Doctoral dissertation, McGill University, Montreal, Canada]. Dissertation Abstracts International, 34 (02), 819B.

Cosper, S. M., Lee, G. P., Peters, S. B., & Bishop, E. (2009). Interactive Metronome training in children with attention deficit and developmental coordination disorders. *International Journal of Rehabilitation Research, 32*(4), 331–336.

Culbertson, W. C., & Zillmer, E.A. (2005). *The Tower of London DX manual*. North Tonawanda, NY: Multi-Health Systems.

D'Elia, L., Satz, P., Uchiyama, C., & White, T. (1996). *Color Trails Test professional manual*. Lutz: Psychological Assessment Resources.

Dane, A. V., & Schneider, B. H. (1998). Program integrity in primary and early secondary prevention: are implementation effects out of control?. *Clinical Psychology Review, 18*(1), 23–45.

De Luca, R., Leonardi, S., Portaro, S., Le Cause, M., De Domenico, C., Colucci, P. V., Pranio, F., Bramanti, P., & Calabro, R. S. (2019). Innovative use of virtual reality in autism spectrum disorder: A case-study. *Applied Neuropsychology: Child*, 1–11.

de Vries, M., Prins, P. J., Schmand, B. A., & Geurts, H. M. (2015). Working memory and cognitive flexibility-training for children with an autism spectrum disorder: A randomized controlled trial. *Journal of Child Psychology and Psychiatry, 56*(5), 566–576.

Elison, J. T., Paterson, S. J., Wolff, J. J., Reznick, J. S., Sasson, N. J., Gu, H., Botteron, K. N., Dager, S. R., Estes, A. M., Evans, A. C., Gerig, G., Hazlett, H. C., Schultz, R. T., Styner, M., Zwaigenbaum, L., & Piven, J. (2013). White matter microstructure and atypical visual orienting in 7-month-olds at risk for autism. *American Journal of Psychiatry, 170*(8), 899–908.

Erickson, L. C., Thiessen, E. D., Godwin, K. E., Dickerson, J. P., & Fisher, A. V. (2015). Endogenously and exogenously driven selective sustained attention: Contributions to learning in kindergarten children. *Journal of Experimental Child Psychology, 138*, 126–134.

Fischer, J., Koldewyn, K., Jiang, Y. V., & Kanwisher, N. (2014). Unimpaired attentional disengagement and social orienting in children with autism. *Clinical Psychological Science, 2*(2), 214–223.

Garon, N., Bryson, S. E., Zwaigenbaum, L., Smith, I. M., Brian, J., Roberts, W., & Szatmari, P. (2009). Temperament and its relationship to autistic symptoms in a high-risk infant sib cohort. *Journal of Abnormal Child Psychology, 37*(1), 59–78.

Gevarter, C., Bryant, D. P., Bryant, B., Watkins, L., Zamora, C., & Sammarco, N. (2016). Mathematics interventions for individuals with autism spectrum disorder: A systematic review. *Review Journal of Autism and Developmental Disorders, 3*(3), 224-238.

Gilliam J. E. (2006). *Gilliam Autism Rating Scale: Second Edition (GARS-2).* Torrance, CA: Western Psychological Services.
Gioia, G. A., Isquith, P. K., Guy, S. C., & Kenworthy, L. (2000). *Behavior rating inventory of executive function: BRIEF*. Odessa, FL: Psychological Assessment Resources.
Goldstein, S., & Naglieri, J. (2011). Neurocognitive and behavioral characteristics of children with ADHD and autism: New data and new strategies. *The ADHD Report, 19*(4), 10–12.Gordon, M. (1979). The assessment of impulsivity and mediating behaviors in hyperactive and nonhyperactive boys. *Journal of Abnormal Child Psychology, 7*(3), 317–326.
Hartman, C.A., Luteijn, E., Serra, M., & Minderaa, R. (2006). Refinement of the children's social behavior questionnaire (CSBQ): An instrument that describes the diverse problems seen in milder forms of PDD. *Journal of Autism and Developmental Disorders, 36*(3), 325–342.
Hopkins, Z., Yuill, N., & Branigan, H. P. (2017). Inhibitory control and lexical alignment in children with an autism spectrum disorder. *Journal of Child Psychology and Psychiatry, 58*(10), 1155–1165.
Hughes, E. M., & Yakubova, G. (2019). Addressing the mathematics gap for students with ASD: An evidence-based systematic review of video-based mathematics interventions. *Review Journal of Autism and Developmental Disorders*, *6*(2), 147-158.
Jones, E. J., Gliga, T., Bedford, R., Charman, T., & Johnson, M. H. (2014). Developmental pathways to autism: a review of prospective studies of infants at risk. *Neuroscience & Biobehavioral Reviews, 39*(100), 1–33.
Kasari, C., & Smith, T. (2013). Interventions in schools for children with autism spectrum disorder: Methods and recommendations. *Autism, 17*(3), 254–267.
Keehn, B., Lincoln, A. J., Müller, R. A., & Townsend, J. (2010). Attentional networks in children and adolescents with autism spectrum disorder. *Journal of Child Psychology and Psychiatry, 51*(11), 1251–1259.
Keehn, B., Müller, R. A., & Townsend, J. (2013). Atypical attentional networks and the emergence of autism. *Neuroscience & Biobehavioral Reviews, 37*(2), 164–183.
Keen, D., Webster, A., & Ridley, G. (2016). How well are children with autism spectrum disorder doing academically at school? An overview of the literature. *Autism, 20*(3), 276–294.
Kendall, J. M. (2003). Designing a research project: randomized controlled trials and their principles. *Emergency Medicine Journal, 20*(2), 164–168.
Kourkoulou, A., Kuhn, G., Findlay, J. M., & Leekam, S. R. (2013). Eye movement difficulties in autism spectrum disorder: implications for implicit contextual learning. *Autism Research*, *6*(3), 177–189.
Kreibich, S. R., Chen, M., & Reichle, J. (2015). Teaching a child with autism to request breaks while concurrently increasing task engagement. *Language, Speech, and Hearing Services in Schools, 46*(3), 256–265.
MacSween, J. V. (2017). *The effects of executive function and attention training for children: The role of motivation and self-concept* [Doctoral dissertation, Faculty of Graduate Studies, University of Victoria]. ETD (Electronic Theses and Dissertations).
Manly, T., Robertson, I. H., Anderson, V., & Mimmo-Smith, I. (1999). *Test of every day attention for children: TEA-Ch.* Bury St Edmunds: Thames Valley Test Company.

May, T., Rinehart, N. J., Wilding, J., & Cornish, K. (2015). Attention and basic literacy and numeracy in children with Autism Spectrum Disorder: A one-year follow-up study. *Research in Autism Spectrum Disorders, 9*, 193–201.
May, T., Rinehart, N., Wilding, J., & Cornish, K. (2013). The role of attention in the academic attainment of children with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 43*(9), 2147–2158.
Mayes, S. D., & Calhoun, S. L. (2007). Learning, attention, writing, and processing speed in typical children and children with ADHD, autism, anxiety, depression, and oppositional-defiant disorder. *Child Neuropsychology, 13*(6), 469–493.
Menazza, C., Bacci, C., & Vio, C. (2010). Parent training nell'autismo. In Programma per la formazione e il supporto dei genitori. Trento: Erickson.
Miller, M., Chukoskie, L., Zinni, M., Townsend, J., & Trauner, D. (2014). Dyspraxia, motor function and visual–motor integration in autism. *Behavioural Brain Research, 269*, 95–102.
Mundy, P., Block, J., Delgado, C., Pomares, Y., Van Hecke, A. V., & Parlade, M. V. (2007). Individual differences and the development of joint attention in infancy. *Child Development, 78*(3), 938–954.
Murphy, C. M., Christakou, A., Daly, E. M., Ecker, C., Giampietro, V., Brammer, M., Johnston, P., Robertson, D. M., Declan, G., Murphy, D. G., & Rubia, K. (2014). Abnormal functional activation and maturation of fronto-striato-temporal and cerebellar regions during sustained attention in autism spectrum disorder. *American Journal of Psychiatry, 171*(10), 1107–1116.
Osterling, J. A., Dawson, G., & Munson, J. A. (2002). Early recognition of 1-year-old infants with autism spectrum disorder versus mental retardation. *Development and Psychopathology,14*(2), 239–251.
Parsons, S., Charman, T., Faulkner, R., Ragan, J., Wallace, S., & Wittemeyer, K. (2013). Commentary–bridging the research and practice gap in autism: The importance of creating research partnerships with schools. *Autism: The International Journal of Research and Practice, 17*(3), 268–280.
Pasiali, V., LaGasse, A. B., & Penn, S. L. (2014). The effect of musical attention control training (MACT) on attention skills of adolescents with neurodevelopmental delays: A pilot study. *Journal of Music Therapy, 51*(4), 333–354.
Patten, E., & Watson, L. R. (2010). Interventions targeting attention in young children with autism. *American Journal of Speech-language Pathology, 20*(1), 60–69.
Pelham Jr, W.E., Gnagy, E.M., Greenslade, K.E., & Milich, R. (1992). Teacher ratings of DSM-III-R symptoms for the disruptive behavior disorders. *Journal of the American Academy of Child and Adolescent Psychiatry, 31*(2), 210–218.
Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience, 35*(1), 73–89.
Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*(1), 3–25.
Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience, 13*(1), 25–42.
Posner, M.I. (1987). Cognitive neuropsychology and the problem of selective attention. In R. J. Ellison, N. M. F. Murray & A. M. Halliday (Eds.), *The London Symposia, EEG Suppl 39* (pp 313-316). New York: Elsevier.

Powell, G., Wass, S. V., Erichsen, J. T., & Leekam, S. R. (2016). First evidence of the feasibility of gaze-contingent attention training for school children with autism. *Autism, 20*(8), 927-937.

Raven, J., Raven, J. C., & Court, J. H. (2008). *Raven's Educational: Coloured Progressive Matrices and Crichton Vocabulary Scale Manual.* London: NCS Pearson.

Raven, J., Raven, J.C., & Court, J.H. (1998). *Manual for Raven's Progressive Matrices and Vocabulary Scales. Section 2: The Coloured Progressive Matrices*. San Antonio, TX: Harcourt Assessment.

Reed, P., Watts, H., & Truzoli, R. (2013). Flexibility in young people with autism spectrum disorders on a card sort task. *Autism, 17*(2), 162–171.

Regard, M., Strauss, E., & Knapp, P. (1982). Children's production on verbal and non-verbal fluency tasks. *Perceptual and Motor Skills, 55*(3), 839–844.

Reichow, B. (2011). Development, procedures, and application of the evaluative method for determining evidence-based practices in autism. In B. Reichow, P. Doehring, D. V. Cicchetti, & F. R. Volkmar (Eds.), *Evidence-based practices and treatments for children with autism* (pp. 25–39). New York, NY: Springer.

Reichow, B., & Volkmar, F. R. (2010). Social skills interventions for individuals with autism: Evaluation for evidence-based practices within a best evidence synthesis framework. *Journal of Autism and Developmental Disorders, 40*(2), 149-166.

Reichow, B., Volkmar, F. R., & Cicchetti, D. V. (2008). Development of an evaluative method for determining the strength of research evidence in autism. *Journal of Autism and Developmental Disorders, 38*(7), 1311-1319.

Rimland, B., & Edelson, S. M. (1999). *Autism treatment evaluation checklist*. San Diego, CA: Autism Research Institute.

Roberts, G., Vaughn, S., Beretvas, S. N., & Wong, V. (Eds.). (2017). *Treatment Fidelity in Studies of Educational Intervention.* New York: Taylor & Francis Group, Routledge.

Robertson, I.H., Manly, T., Andrade, J., Baddeley, B.T., & Yiend, J. (1997). Oops!': Performance correlates of everyday attentional failures in traumatic brain injured and normal subjects. *Neuropsychologia*, 35(6), 747–758.

Rose, V., Trembath, D., & Bloomberg, K. (2016). Visual attention and key word sign in children with autism spectrum disorder. *Journal of Developmental and Physical Disabilities, 28*(1), 33–55.

Sacrey, L. A. R., Armstrong, V. L., Bryson, S. E., & Zwaigenbaum, L. (2014). Impairments to visual disengagement in autism spectrum disorder: a review of experimental studies from infancy to adulthood. *Neuroscience & Biobehavioral Reviews, 47*, 559–577.

Sarzyńska, J., Żelechowska, D., Falkiewicz, M., & Nęcka, E. (2017). Attention training in schoolchildren improves attention but fails to enhance fluid intelligence. *Studia Psychologica, 59*(1), 50–65.

Schietecatte, I., Roeyers, H., & Warreyn, P. (2012). Exploring the nature of joint attention impairments in young children with autism spectrum disorder: Associated social and cognitive skills. *Journal of Autism and Developmental Disorders, 42*(1), 1–12.

Schopler, E. C., Reichler, R., & Renner, B. (1988). *The Childhood Autism Rating Scale (CARS).* Los Angeles, CA: Western Psychological Services.

Schopler, E., Reichler, R. J., DeVellis, R. F., & Daly, K. (1980). Toward objective classification of childhood autism: Childhood Autism Rating Scale (CARS). *Journal of Autism and Developmental Disorders, 10*(1), 91–103.

Schopler, E., Van Bourgondien, M. E., Wellman, G. J., & Love, S. R. (2010). *Childhood Autism Rating Scale–Second Edition (CARS-2).* Los Angeles, CA: Western Psychological Services.

Senju, A., Tojo, Y., Dairoku, H., & Hasegawa, T. (2004). Reflexive orienting in response to eye gaze and an arrow in children with and without autism. *Journal of Child Psychology and Psychiatry, 45*(3), 445–458.

Shaffer, R. J., Jacokes, L. E., Cassily, J. F., Greenspan, S. I., Tuchman, R. F., & Stemmer, P. J. (2001). Effect of Interactive Metronome® training on children with ADHD. *American Journal of Occupational Therapy, 55*(2), 155–162.

Shalev, L., Tsal, Y., & Mevorach, C. (2007). Computerized progressive attentional training (CPAT) program: Effective direct intervention for children with ADHD. *Child Neuropsychology, 13*(4), 382–388.

Spaniol, M. M., Shalev, L., Kossyvaki, L., & Mevorach, C. (2018). Attention training in autism as a potential approach to improving academic performance: a school-based pilot study. *Journal of Autism and Developmental Disorders, 48*(2), 592–610.

Steiner, N. J., Frenette, E., Hynes, C., Pisarik, E., Tomasetti, K., Perrin, E. C., & Rene, K. (2014). A pilot feasibility study of neurofeedback for children with autism. *Applied Psychophysiology and Biofeedback, 39*(2), 99–107.

Stern, P., & Shalev, L. (2013). The role of sustained attention and display medium in reading comprehension among adolescents with ADHD and without it. *Research in Developmental Disabilities, 34*(1), 431–439.

Stevens, C., & Bavelier, D. (2012). The role of selective attention on academic foundations: A cognitive neuroscience perspective. *Developmental Cognitive Neuroscience, 2,* S30–S48.

Thorndike, R. L., Hagen, E. P., & Sattler, J. M. (1986). *Stanford-Binet Intelligence Scale* (4th ed.). Chicago, IL: Riverside.

Townsend, J., Westerfield, M., Leaver, E., Makeig, S., Jung, T. P., Pierce, K., & Courchesne, E. (2001). Event-related brain response abnormalities in autism: evidence for impaired cerebello-frontal spatial attention networks. *Cognitive Brain Research, 11*(1), 127–145.

Tse, C. Y. A., Lee, H. P., Chan, K. S. K., Edgar, V. B., Wilkinson-Smith, A., & Lai, W. H. E. (2019). Examining the impact of physical activity on sleep quality and executive functions in children with autism spectrum disorder: A randomized controlled trial. *Autism, 23*(7), 1699-1710.

Tucha, O., Tucha, L., Kaumann, G., König, S., Lange, K. M., Stasik, D., Streather, Z., Engelschalk, T., & Lange, K. W. (2011). Training of attention functions in children with attention deficit hyperactivity disorder. *ADHD Attention Deficit and Hyperactivity Disorders, 3*(3), 271–283.

Wallace, G. L., Yerys, B. E., Peng, C., Dlugi, E., Anthony, L. G., & Kenworthy, L. (2016). Assessment and treatment of executive function impairments in autism spectrum disorder: An update. In R. M. Hodapp & D. J. Fidler (Eds.), *International Review of Research in Developmental Disabilities* (Vol. 51, pp. 85–122). New York, NY: Academic Press.

Wang, S., Jiang, M., Duchesne, X. M., Laugeson, E. A., Kennedy, D. P., Adolphs, R., & Zhao, Q. (2015). Atypical visual saliency in autism spectrum disorder quantified through model-based eye tracking. *Neuron, 88*(3), 604-616.

Wang, S., Xu, J., Jiang, M., Zhao, Q., Hurlemann, R., & Adolphs, R. (2014). Autism spectrum disorder, but not amygdala lesions, impairs social attention in visual search. *Neuropsychologia, 63,* 259-274.

Wass, S. V., Jones, E. J., Gliga, T., Smith, T. J., Charman, T., & Johnson, M. H. (2015). Shorter spontaneous fixation durations in infants with later emerging autism. *Scientific Reports*, *5*(1), 1–8.

Wass, S. V., Scerif, G., & Johnson, M. H. (2012). Training attentional control and working memory–Is younger, better?. *Developmental Review, 32*(4), 360–387.

Wigal, S. B., & Wigal, T. L. (2006). The laboratory school protocol: Its origin, use, and new applications. *Journal of Attention Disorders*, *10*(1), 92–111.

William, J., Rickert, V., Hogan, J., Zolten, A. J., Satz, P., D'Elia, L. F., Asarnow, R. F., Zaucha, K., & Light, R. (1995). Children's Color Trails. *Archives of Clinical Neuropsychology, 10*(3), 211–223.

Watkins, L., O'Reilly, M., Kuhn, M., Gevarter, C., Lancioni, G. E., Sigafoos, J., & Lang, R. (2015). A review of peer-mediated social interaction interventions for students with autism in inclusive settings. *Journal of Autism and Developmental Disorders, 45*(4), 1070-1083.

Whalon, K. J., Conroy, M. A., Martinez, J. R., & Werch, B. L. (2015). School-based peer related social competence interventions for children with autism spectrum disorder: A meta-analysis and descriptive review of single case research design studies. *Journal of Autism and Developmental Disorders*, *45*(6), 1513-1531.