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REVIEW PAPER

A Meta-Analysis of Applied Behavior Analysis-Based Interventions to Improve Communication, Adaptive, and Cognitive Skills in Children on the Autism Spectrum

Isabella Mutschler Collins[1,2] · Franziska Halter[1] · Leila T. Schächinger Tenés[3] · Roselind Lieb[1] · Andrea H. Meyer[1]

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Abstract
This meta-analysis examined the effectiveness of Applied Behavior Analysis-based (ABA) interventions, including Naturalistic Developmental Behavioral Interventions (NDBI), in improving communication, adaptive, and cognitive skills as well as severity of challenging characteristics in children identified as being on the autism spectrum. Furthermore, our investigation extended to the evaluation of potential moderator variables. Twenty-five studies meeting the inclusion criteria were identified. Pre- to post-intervention effects were compared between experimental and control groups. Compared to control-groups ABA-based interventions revealed a large effect size for receptive language skills and moderate effect sizes for adaptive, and cognitive skills. Meta-regression revealed that ABA-based interventions with greater treatment dose and duration yielded greater improvements in adaptive behaviors. Implications for future research and practice are being discussed.

Keywords Autism spectrum disorders · Intervention · Child · Systematic review · Meta-analysis · Meta-regression

Introduction

According to the ICD-11, autism spectrum disorder (ASD) is defined by (1)"persistent deficits in the ability to initiate and sustain reciprocal social interaction and social communication, (2) a range of restricted, repetitive, and inflexible patterns of behavior, interests or activities, (3) and symptoms result in significant impairment in personal, family, social, educational, occupational or other important areas of functioning"(World Health Organization, 2019). In addition to differences and potential challenges in behavior, ICD-11 also specifies that individuals on the autism spectrum may have a diverse range of intellectual and language abilities. While the onset of autism spectrum characteristics typically occurs in early development, it is acknowledged by ICD-11 that observable traits, like challenges in sustaining reciprocal interactions, may often fully manifest later, during adolescence or even adulthood, particularly when social demands exceed an individual's compensatory abilities. An early diagnosis, as well as an early onset of effective treatment, are considered crucial in helping individuals on the autism spectrum develop strategies for their behavioral, communicative, and cognitive differences that support them in their daily lives and development (Granpeesheh et al., 2009; Hyman et al., 2020). This study aims to determine whether Applied Behavioral Analysis-based interventions (ABA) serve as such an effective strategy, and whether further treatment-related factors, such as treatment duration or intensity among others, may moderate and improve the intervention's success.

The identification of communication differences and challenges is frequently a primary concern in children with suspected of being on the autism spectrum. Retrospective analyses have revealed early communication differences in children on the autism spectrum at 12 months, such as showing less joint attention, orienting less to speech, producing fewer phrases, and generating fewer gestures (Mitchell et al., 2006; Osterling & Dawson, 1994). A smaller number of children on the autism

✉ Isabella Mutschler Collins
isabella.collins@unibas.ch

1 Faculty of Psychology, Division of Clinical Psychology and Epidemiology, University of Basel, Missionsstrasse 62a, 4055 Basel, Switzerland

2 University Psychiatric Clinics Basel, Wilhelm Klein Strasse 27, Basel 4002, Switzerland

3 Faculty of Psychology, Division of Developmental and Personality Psychology, University of Basel, Missionsstrasse 62a, 4055 Basel, Switzerland

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spectrum even experience a loss or regression in previously acquired language skills (Kurita, 1985; Lord et al., 2004). However, good language skills are beneficial, as strong language skills in childhood have been linked to positive social and behavioral outcomes in adolescents and adults on the autism spectrum (Magiati et al., 2014; Miranda et al., 2023). This underscores the significance of early psychological interventions aiming to improve communication skills in children on the autism spectrum. Furthermore, children on the autism spectrum often exhibit differences and challenges in adaptive behaviors (Pugliese et al., 2015). Improving adaptive skills through psychological interventions appears particularly relevant when challenging behaviors emerge in response to difficult daily routines, where challenges in adaptive skills may be present (e.g., during dressing or bathing). Widely utilized interventions for managing characteristics associated with autism spectrum disorder (ASD) in children include Applied Behavior Analysis (ABA), pioneered by Lovaas (1987, 2003), and Naturalistic Developmental Behavioral Interventions (NDBI). NDBIs blend principles from both ABA and developmental psychology (Bruinsma et al., 2020; Schreibman et al., 2015). ABA, according to Lovaas (1987, 2003), applies discrete trial training to improve communication skills, adaptive behavior, and cognitive skills in children on the autism spectrum (Eldevik et al., 2009; Peters-Scheffer et al., 2011; Reichow et al., 2012). During isolated learning trials comprising a prompt, an instruction, the child's behavior and a subsequent reinforcement, children learn small behavior components, which are then gradually integrated into longer sequences (Lovaas, 1987). Several meta-analyses comparing treatment groups with control groups favored this approach, especially in the areas of intellectual functioning (Eldevik et al., 2009; Peters-Scheffer et al., 2011; Reichow et al., 2012). Among NDBI, there are various models, such as Project ImPACT (Improving Parents as Communication Teachers; Ingersoll & Dvortcsak, 2019), Pivotal Response Treatment (PRT; Koegel & Koegel, 2018), and Early Start Denver Model (ESDM; Rogers & Dawson, 2009), all of which contain the following core components: (a) Teaching caregivers to create learning opportunities in their child's natural environment (i.e., in the context of play and daily routines) that follow the child's interests, (b) ensuring child-caregiver interactions are child-initiated and motivation-based, and (c) employing developmental-enhancing learning strategies such as modeling, shaping, chaining, prompting, and reinforcement by using natural reward contingencies (Bruinsma et al., 2020; Schreibman et al., 2015). Previous meta-analyses that exclusively incorporated NDBI-based treatment groups and control-group designs reported small to moderate effect sizes for social communication, cognitive skills and challenging autism spectrum traits (Crank et al., 2021; Sandbank et al., 2020a; Tiede & Walton, 2019; Uljarevic et al., 2021; Wang et al., 2022). Beside the specific theories and treatment manual underlying the intervention, research has also identified factors that may moderate the impact of ABA-based treatments on developmental outcomes. If children were younger at the beginning of the intervention (Granpeesheh et al., 2009), received treatment with high intensity and duration (Klinger et al., 2021; Linstead et al., 2017), as well if the intervention was implemented by clinicians, or clinicians and caregivers combined (rather than interventions implemented by caregivers alone; Sandbank et al., 2020b), treatment outcomes were positively affected.

This meta-analysis aimed to provide an updated examination of the effectiveness of ABA-based interventions in improving communication and adaptive skills in children identified on the autism spectrum. This study also examined improvements in the domain of cognitive skills and reductions of challenging autism spectrum traits. To our knowledge, this meta-analysis is the first to focus on the combination of ABA according to Lovaas (1987, 2003) and three NDBI models: PRT (Koegel & Koegel, 2018), Project ImPACT (Ingersoll & Dvortcsak, 2019), and ESDM (Rogers & Dawson, 2009). To ensure methodological quality, only pre-post studies with a control group were included and a study quality assessment was performed. In this study, the age range of 1.5 to 10 years was selected because treatment recommendations for children on the autism spectrum emphasize early interventions (Hyman et al., 2020).

Furthermore, our aim was to analyze potential moderator variables, therefore, a meta-regression analysis was conducted. Based on previous research, it was hypothesized that the following moderators would positively impact treatment outcome variables, including expressive and receptive language, adaptive behavior, and cognitive skills: (1) children younger at the beginning of the intervention, (2) a greater treatment dose, (3) a longer treatment duration, and (4) if the intervention was implemented by clinicians or clinicians and caregivers combined rather than interventions implemented by caregivers alone, (5) if the therapist received supervision during treatment, and (6) setting, i.e., if treatment was delivered within a University-based study or in a community-based setting.

Method

The protocol for this meta-analysis was registered in PROSPERO (registration number CRD42023394509). This study was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; Page et al., 2021).

Search Strategy

Studies eligible for the meta-analyses were identified by a comprehensive literature search in MEDLINE, Web of Science, PsycINFO, EMBASE, Scopus and Cochrane Library and ProQuest. To minimize publication bias, unpublished studies (dissertations and theses) were also included in our literature search. We identified additional studies by searching reference lists of primary articles, reviews, and meta-analyses and by contacting experts in the field (date of last search was 08/09/2023).

The following keywords/search terms were applied in English, French or German: autism spectrum disorder(s), ASD(s), EIBI, applied behavior analysis, ABA, Early Start Denver Model, ESDM, ImPACT, pivotal response treatment, PRT, preschool children, children, Autismus Spektrum Störung, ASS, Autismus, EIBI, ABA, Vorschulkinder, Kinder, Trouble du Spectre de l'Autisme, TSA, Autisme, AAC, ICI, enfants préscolaire, enfants.

Inclusion Criteria and Selection of Studies

Studies included in meta-analysis had to meet the following criteria: 1) Children had received an ASD-diagnosis according to the ICD-10 (World Health Organisation, 2007), DSM-IV (American Psychiatric Association, 1994) or DSM-5 (American Psychiatric Association, 2013). Due to inclusion of very young children, an elevated likelihood for a later diagnosis of autism spectrum disorder (EL-ASD) was accepted, too. 2) Studies had to include a control group as well as pre-post- comparisons (i.e., randomized controlled trials (RCT) or non-randomized control group designs). Single case reports and group studies without control groups were excluded. 3) Treatment group had at least five participants, and 4) the treatment group had to receive comprehensive ABA-based intervention according to Lovaas or one of the ABA-based NDBI models: PRT, Project ImPACT, or ESDM. 5) Control groups received service as usual (SAU), treatment as usual (TAU), or eclectic treatment, which was allowed to include ABA-elements among other approaches. 6) At least one child-related outcome (receptive and expressive language skills, adaptive skills, IQ/cognitive skills, and/or autism severity) was reported, and the mean and standard deviation for each outcome variable were provided by the authors for the treatment and control groups at pre-post measures. 7) Study had to be published in English, German or French. 8) Children`s mean age at intake had to be between 1.5 and 9.9 years of age. The search results were imported into EndNote (Version 20) and then transferred to Covidence (https://www.covidence.org), which was used in the study screening and selection process. After removing duplicates, two independent reviewers (FH & IMC) screened first by title and abstract, followed by full-text screening. Any disagreements were resolved through discussion between the two reviewers.

Data Extraction

Two authors (FH & IMC) independently extracted data regarding study design, descriptions of the study population, comparison group, intervention, setting, and outcome variables. They reviewed each study, and any inconsistencies were discussed to reach a consensus. For each study, the following information was extracted: 1) First author's name and year of publication. 2) The country where the study was conducted. 3) The sample size for the treatment group and control group. If mentioned, the number of boys and girls was provided. 4) Information what kind of treatment the control group received. 5) Information about the mean age (and standard deviation or range) of the participants in months. 6) The setting (center, school, home, combined) of the treatment and by whom it was delivered (e.g., clinician, therapist) for the treatment group. 7) If caregivers were actively involved in the treatment for the treatment group. 8) If therapists received supervision in the treatment group. 9) The treatment duration for the treatment group (in months). 10) The intensity of the treatment in hours per week for the treatment group. 11) Which outcome assessments relevant to this meta-analysis were applied.

The mean and standard deviation for the treatment and control group at pre- and post-treatment were entered into an Excel sheet and independently verified by two authors, FH and ICM, regarding the accuracy of the data.

Study Quality Appraisal

All 25 studies were appraised using a checklist that we created based on previously published research (Des Jarlais et al., 2004; Detsky et al., 1992; Smith et al., 2007). The checklist included the following 14 criteria: 1) Was the study pre-registered? 2) Was the sample size pre-justified? 3) Was the recruitment process and inclusion criteria explained? 4) Did the study include a random treatment assignment? 5) Did the study include an assessment of baseline IQ and other characteristics? 6) Did the study explain the intervention? 7) Was treatment fidelity/adherence monitored? 8) Did the therapist receive supervision? 9) Did the study use validated measures to assess outcome variables? 10) Were the assessors blinded to treatment assignment? 11) Did the study report parent-outcome variables (e.g., parenting stress)? 12)

Did the study describe the number of dropouts? 13) Did the study assess parents'perspectives on treatment acceptability and satisfaction with their child's treatment outcomes? 14) Did the study include follow-up assessments? Two authors (FH & IMC) independently appraised each study, and disagreements were discussed until consensus was reached. Assessing these quality criteria ensures the reliability and validity of a meta-analysis. Pre-registration and sample justification enhance transparency, while clear recruitment and random assignment reduce bias. Baseline assessments provide a comparison between groups. Treatment fidelity, and therapist supervision ensure interventions are delivered as intended, affecting the outcomes' credibility. Validated outcome measures, blinded assessors, and dropout reporting improve result accuracy. Parent-reported outcomes and treatment acceptability provide broader insight, and follow-ups assess long-term effects. These factors collectively strengthen the meta-analysis by ensuring methodological rigor and generalizability.

Statistical Analyses

Meta-Analyses

Nine meta-analyses were conducted for the following nine outcomes: 1) receptive language skills, 2) expressive language skills, 3) adaptive behavior in communication, 4) adaptive behavior in daily living, 5) adaptive behavior in socialization, 6) adaptive behavior in motor skills, 7) adaptive behavior composite, 8) cognitive skills, and 9) reduction in symptoms of ASD. The meta-analysis of expressive language skills was re-analyzed by excluding one study (Fava et al., 2011) that was identified as potential outlier using a boxplot. Calculations for the meta-analysis were conducted with the R-package metafor version 4.4–0 (Viechtbauer, 2010). This study compared pre- to post-intervention effects between experimental and control groups. Standardized mean change (*SMC)* together with their corresponding confidence intervals were calculated according to Morris (2008), thereby assuming a correlation between pre and post intervention of 0.6 for each outcome. An effect size of 0.2, 0.5, and 0.8 is considered to be small, moderate, and large, respectively (Cohen, 1988). We used a random-effects model, thus, assuming that the observed effect sizes vary across studies because of both real differences in the treatment effects and chance (sampling error). Prediction intervals were computed to assess the amount of between-study heterogeneity (Spineli & Pandis, 2020). These indicate the interval within which the effect size of a new study would fall if this study was selected at random from the same population of the studies already included in the meta-analysis. Results are presented as forest plots, which first show the distribution of *SMC*s and confidence intervals of the individual studies and on the bottom averaged across all studies. A vertical line drawn through $SMC = 0$ indicates the cut-off for the confidence intervals denoting significant results. The presence of a publication bias was assessed through a visual inspection of the asymmetry of funnel plots (Sterne & Egger, 2001). All statistical analyses were conducted with the statistic program R (Version 4.3.0).

Meta-Regression Analysis

Five potential moderators were specified: 1) child's age at the beginning of therapy (sample mean in months), 2) treatment dose (number of sessions and session lengths, yielding total treatment time in minutes), 3) treatment duration (in weeks), 4) caregiver involvement in therapy (0 = if the intervention was implemented by clinicians alone, 1 = if intervention was implemented by clinicians and caregivers combined ("caregiver involvement"), 5) if the therapist received supervision during treatment (1 = yes, 0 = no). The moderator setting, specifically whether the treatment was delivered within a university-based study or a community-based setting, was not sufficiently specified in our studies. Consequently, this moderator has been excluded from the analysis.

Results

Study Sample Characteristics

Figure 1 shows the flow diagram adapted from the PRISMA Statement (Page et al., 2021). The diagram illustrates the process of identification and screening, eligibility assessment, and inclusion of studies. 3314 studies were identified through database searching in PubMed, Scopus, PsycINFO and 212 studies through other sources such in other meta-analyses. After removing duplicates, 1476 studies entered the title and abstract screening process. After the screening process, 138 studies were eligible for full-text review. Among them, 113 studies were excluded during the full-text review for the following reasons: 12 due to wrong outcomes, 4 due to the wrong age group, 68 due to the wrong study design (e.g., case studies or studies without appropriate control groups), 1 due to not being published in English, German, or French, 10 due to the wrong patient groups, 13 due to not having provided pre-post measures, mean, and/or standard deviation, and finally, 5 due to other reasons (e.g., unclear assessment methods). Twenty-five studies identified in the initial literature search satisfied the inclusion criteria (Bejarano-Martin et al., 2022; Dawson et al., 2010; Devescovi et al., 2021; Eikeseth et al., 2002, 2012; Eldevik et al., 2006, 2012; Fava et al., 2011; Flanagan et al., 2012; Gengoux et al., 2019; Grindle et al., 2012; Holzinger et al.,

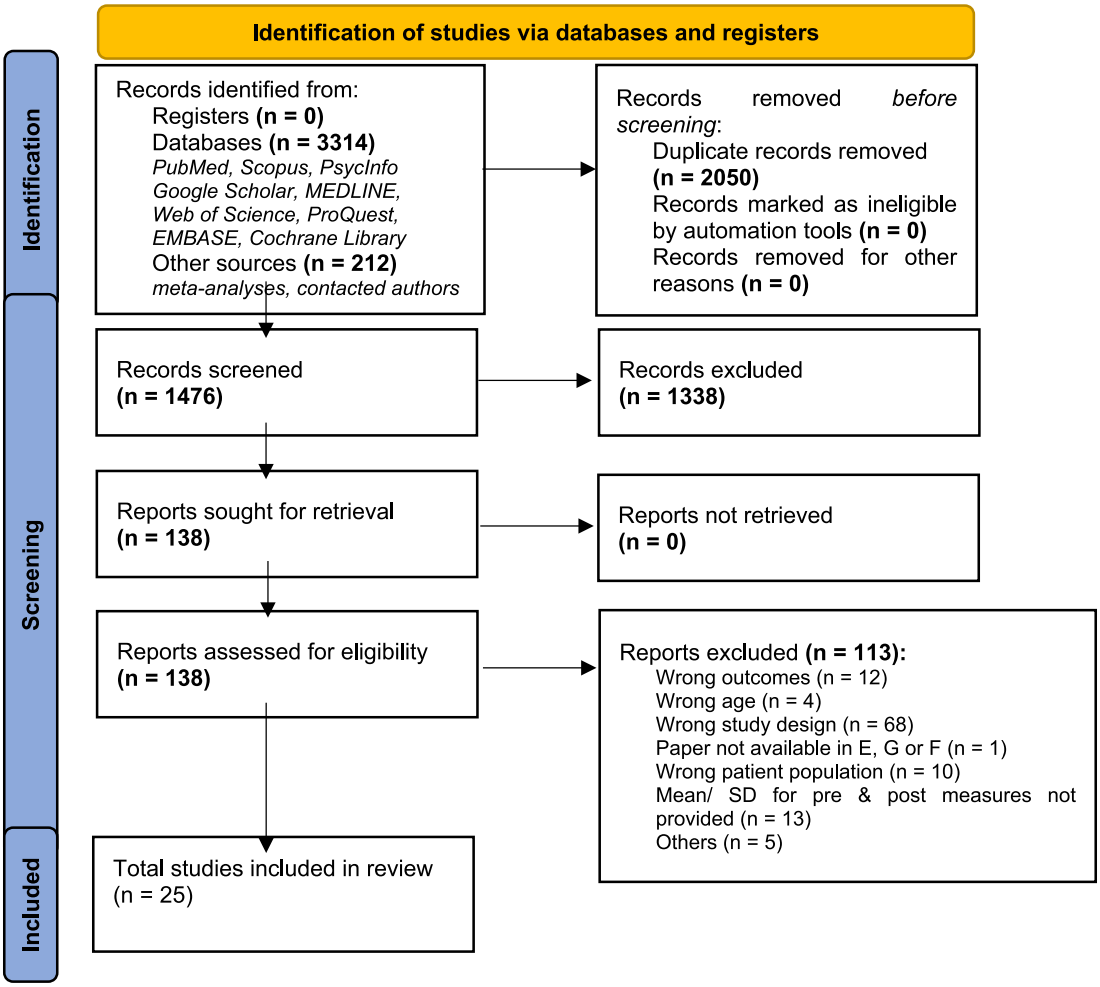


Fig. 1 PRISMA Flow Chart (Page et al., 2021)

2019; Peters-Scheffer et al., 2010; Reed et al., 2007; Remington et al., 2007; Schreibman & Stahmer, 2014; Sheinkopf & Siegel, 1998; Sinai-Gavrilov et al., 2020; Stadnick et al., 2015; Stahmer et al., 2020; Stanislaw et al., 2020; Vivanti et al., 2014; Wang et al., 2023; Waters et al., 2020; Xu et al., 2018). The main characteristics of these studies are presented in Table 1.

Outcome Measures

Language skills were administered using the British Picture Vocabulary Scale (BPVS; Dunn et al., 1997), cognitive verbal performance subtest of the Psychoeducational Profile-Revised (PEP; Schopler et al., 1990), Reynell Development Language Scale (RDLS; Reynell, 1990), receptive and expressive language subscales of the Mullen Scales of Early Learning (Mullen, 1995), receptive and expressive communication scores of the ESDM Curriculum Checklist (Rogers & Dawson, 2009), the Expressive One-Word Picture Vocabulary Test (Brownell, 2000a), the Receptive One-Word Picture Vocabulary Test (Brownell, 2000b), and the MacArthur Communication Developmental Inventories (CDI; Fenson et al., 2000).

Adaptive behavior was assessed within all studies that entered our meta-analyses with the Vineland Adaptive Behavior Scales (VABS; Sparrow et al., 2005). The VABS is composed of five subcategories and a final composite score. The subcategories measure communication, daily living skills, socialization and optionally motor skills.

Cognitive skills were assessed using the Bayley Scales of Infant Development (BSID; Bayley, 1993), Leiter International Performance Scale (Roid & Miller, 1997), Merrill-Palmer Scale of Metal Test (MP; Stutsman, 1948), cognitive performance subtest of the Psychoeducational Profile-Revised (PEP; Schopler et al., 1990), Stanford-Binet Intelligence Scale (SB; Thorndike et al., 1986), Wechsler Preschool and Primary Scales of Intelligence (WPPSI; Wechsler, 1990), the composite score of the Mullen Scales of Early Learning (Mullen, 1995), the Wechsler Intelligence

Table 1 Summary of Characteristics of the Studies

Study: Authors, year of publication, country	Design	Sample characteristics kind of treatment sample size (number of males) Age in months		ABA/NDBI Treatment (TG)				
		Treatment group (TG)	Controlgroup (CG)	setting/intervention implemented by	parent involve-ment	super-vision	treat-ment duration (weeks)	intensity (hours/week)
Bejarano – Martín et al., 2022 Spain	Non RCT	**ImPACT** $n = 6$ (5) $M = 19.17$ ($SD = 0.41$)	**TAU** $n = 5$ (4) $M = 20.0$ ($SD = 1.5$)	center/ by research assistant	yes	no data	15	2
Dawson et al., 2010 USA	RCT	**ESDM** $n = 24$ (18) $M = 23.1$ ($SD = 3.9$, 18–30)	**A/M group** $n = 24$ (19) $M = 23.9$ ($SD = 4.0$, 18–30)	home/ by therapist & parents	yes	yes	104	20
Devescovi et al., 2021 Italy	Non RCT	**ESDM** $n = 19$ (17) $M = 29.6$ ($SD = 9.5$, 19–43)	**TAU** $n = 19$ (15) $M = 30.5$ ($SD = 3.3$, 24–36)	center/ by therapist	yes	no data	52	2
Eikeseth et al., 2002 Norway	Non-RCT	**ABA** $n = 13$ (8), $M = 66.31$ months ($SD = 11.3$)	**Eclectic treatment** $n = 12$ (11), $M = 65.00$ months ($SD = 10.9$)	school/ by therapists	yes	yes	52	$M = 28$ ($SD = 5.76$, range = 20–35)
Eikeseth et al., 2012 Norway, Sweden	Non-RCT	**ABA** $n = 35$ (29), $M = 47$ (range = 25–76)	**eclectic special education teaching** $n = 24$ (20), $M = 53$ (range = 24–88)	home & school/ by therapists	yes	yes	104	$M = 23$ ($SD = 5.3$, range = 15–37)
Eldevik et al., 2006 Norway	Non-RCT	**ABA** $n = 13$, $M = 53$ ($SD = 9.5$, range = 36–68)	**Eclectic treatment** $n = 15$, $M = 49$ ($SD = 16.9$, range = 21–69)	school/ by therapists	yes	yes	80	$M = 12.5$ ($SD = 1.9$, range = 10–15)
Eldevik et al., 2012 Norway	Non-RCT	**ABA** $n = 31$ (25), $M = 42.2$ ($SD = 9$, range = 26–70),	**TAU** $n = 12$ (8), $M = 46.2$ ($SD = 12.4$, range = 24–67)	school/ by an intervention team	no	yes	104	$M = 13.6$

Table 1 (continued)

Study: Authors, year of publication, country	Design	Sample characteristics kind of treatment sample size (number of males) Age in months		ABA/NDBI Treatment (TG)				
		Treatment group (TG)	Controlgroup (CG)	setting/intervention implemented by	parent involve-ment	super-vision	treat-ment duration (weeks)	intensity (hours/week)
Fava et al., 2011 Italy	Non-RCT	**ABA** $n = 12$ (10), $M = 52.0$ ($SD = 19.5$, range = 26–81)	**Eclectic** $n = 10$ (9), $M = 43.7$ ($SD = 26$.range = 28–66)	Center & home/ By teacher & parents	yes	yes	52	Alternating: ~ 26 (center) ~ 12 (home)
Flanagan et al., 2012 Canada	Non-RCT	**ABA** $n = 61$ (53), $M = 42.93$ ($SD = 11.53$)	**Waitlist** $n = 61$ (51), $M = 42.79$, ($SD = 10.51$)	Center & home/ by service professionals	no	no	111	$M = 25.81$ ($SD = 3.44$, range = 20 −35)
Gengoux et al., 2019 USA	RCT	**PRT - P** $n = 23$ (21) $M = 49.5$ ($SD = 11.2$)	**DTG** $n = 20$ (17) $M = 47.2$ ($SD = 10.0$)	home/ by clinician & parent	yes	yes	24	week 1 −12: 1 (parent - training) & 10 (clinician)/ week 13–24: 1 hr/month (parent - training) & 5 (clinician)
Grindle et al., 2012UK	Non-RCT	**ABA**$n = 11$ (9), $M = 58.2$ (range = 43–68)	**Education-as-usual** $n = 18$ (18),$M =$ 63.89,(range = 54–72)	school/by therapist	no	yes	104	$M = 16$ ($SD = 3.6$, range = 8.75–18.75)
Holzinger et al., 2019Austria	NonRCT	**ESDM**$n = 7$ (7)$M = 42.3$ ($SD = 6.0$)	**CG**$n = 6$ (6)$M = 44.5$ ($SD = 8.2$)	school, center & home/by therapists	yes	yes	52	4.6($SD = 0.57$)
Peters-Scheffer, 2010 Netherlands	Non-RCT	**ABA** $n = 12$, $M =$ 53.50($SD = 5.52$, range = 42–62)	**Group program**$n = 22$, $M = 52.95$(SD = 11.14, range = 38–75)	school/by trainers & teachers	yes	yes	32	$M = 6.29$ ($SD = 1.31$, range = 5–10)
Reed et al., 2007UK	Non-RCT	**ABA** $n = 12$ (11), $M = 40$ (range = 32–47),	**Portage** $n = 16$,$M = 38$ (range = 30–45)	home/by therapist	no	yes	40	$M = 30.4$ (range = 20–40).
Remington et al., 2007UK	Non-RCT	**ABA**$n = 23$,$M = 35.7$($SD = 4.0$)	**TAU** $n = 21$, $M = 38.4$ ($SD = 4.4$)	home/by trained tutors	yes	yes	104	M= 25.6 ($SD = 4.8$, range = 18.4–34)
Schreibman & Stahmer, 2014USA	RCT	**PRT**$n = 20$ (18)$M =$ 29.5($SD = 6.9$)	**PECS**$n = 19$ (16)$M =$ 28.9($SD = 4.2$)	center & home/by student therapists	yes	yes	23	week 1–15:4 (labora-tory) & 10 (home)week 16–232 (laboratory) & 4(home)

Table 1 (continued)

Study: Authors, year of publication, country	Design	Sample characteristics kind of treatment sample size (number of males) Age in months		ABA/NDBI Treatment (TG)				
		Treatment group (TG)	Controlgroup (CG)	setting/intervention implemented by	parent involve-ment	super-vision	treat-ment duration (weeks)	intensity (hours/week)
Sheinkopf & Siegel, 1998USA	Non-RCT	**ABA** n =11,M = 33.8 (SD = 6.2,range = 23–47)	**Conventional school-based & brief one-on-one interventions** n = 11,M = 35.3 (SD = 5.5, range = 30–47)	school/by therapists	yes	no	81	M = 27.02 (SD = 7.9),
Sinai –Gavrilov et al., 2020Israel	Non RCT	**PB- ESDM**n = 26 (20)M = 43.65 (SD = 7.37)	**MDI**n = 25 (22)M = 45.12 (SD = 4.8)	school/by therapists	yes	yes	32	44
Stahmer et al., 2019USA	NonRCT	**ImPACT**n = 12 (11)M = 23.08 (SD = 4.31)	**UC**n = 13 (6)M = 22.46 (SD = 5.82)	home or center/by trained providers	yes	no data	12	2.5(SD = 0.90)
Stadnick et al., 2015USA	Non-RCT	**ImPACT**n = 16 (13)M = 46.75 (SD = 25.88)	**Comparison** n = 14 (11) M = 64.07 (SD = 22.32)	center/by clinicians	yes	no data	12	1
Stanislaw et al., 2020USA	Non-RCT	**ABA**n = 50M = 30.10 (SD = 5.14)	**Eclectic treatment**n = 32M = 37.13(SD = 5.72)	home, school & clinic/by clinicians	no	yes	195	25–40
Vivanti et al., 2014Australia	Non – RCT	**ESDM**n = 27 (23)M = 40.3 (SD = 9.55)	**generic intervention**n = 30 (27)M = 41.97 (SD = 6.71)	center/by interdisciplinary team	yes	no data	52	15–25
Wang et al., 2023China	RCT	**PRT**n = 15 (12)M = 72 (SD = 12, range = 60–108)	**TAU**n = 15 (10)M = 72(SD = 12,range = 48–96)	School, center & home/by therapist & parents	yes	no data	10	1.75(languageintervention) + 3.5 (parent training)
Waters et al., 2020USA	Non-RCT	**ABA**n = 48 (45)M = 37.75	**SAU**n = 46 (45)M = 42.59	school/by interventionists,collaborated with teacher	yes	yes	156	35–40
Xu et al., 2018China	RCT	**ESDM**n = 16 (14)M = 47.5 (SD = 6.2)	**eclectic services**n = 20 (18)M = 42.9 (SD = 8.3)	school/by teachers	yes	no	8	

Table 1 summarizes the characteristics of the studies included in the meta-analysis. Abbreviations: ABA = Aplied Behavior Analysis, ESDM = Early Start Denver Model, Non-RCT = non-randomized controlled trial, PB-ESDM = preschool-based ESDM, RCT = randomized controlled trial, SAU = service-as-usual, TAU = treatment-as-usual, UC = usual care. n = sample size, M = mean, SD = standard deviation.

Scale for Children–Revised (WISC-R; Wechsler, 1974), the Cattell Infant Intelligence Scale (Cattell, 1960) and the Snijders-Oomen non-verbal intelligence test-revised (SON-R 2.5–7; Snijders et al., 1996).

Autism symptom severity was assessed using the Autism Diagnostic Observation Schedule (ADOS; Lord, 1999), the Gilliam Autism Rating Scale (GARS; Gilliam, 1995) and the Childhood Autism Rating Scale (CARS; Schopler et al., 2002).

Moreover, some studies (Eldevik et al., 2006; Peters-Scheffer et al., 2010; Reed et al., 2007; Remington et al., 2007; Wang et al., 2023) assessed some specific aspects of maladaptive behaviors with pre-post measures in the experimental- and control group. However, the measurements were too heterogenous to provide a valid meta-analytical evaluation.

Study Quality Assessment

Two of the studies were pre-registered, two studies pre-justified sample-size, all studies explained recruitment and inclusion criteria, five studies applied random treatment assignment, all studies provided assessment of baseline IQ, all studies explained the intervention, 14 studies provided information on treatment fidelity/adherence, 15 studies reported that the therapist who provided treatment received supervision. All studies applied measures that were validated, 14 studies reported that the assessors were blinded to treatment assignment, six studies reported also parent-outcomes (parental stress, parental well-being, parental, parental satisfaction with the intervention), and 18 studies described potential dropouts. Moreover, seven studies assessed parents'perspectives on treatment acceptability and satisfaction regarding their child's treatment outcomes and three studies provided follow-assessments. On average each study met six to seven out of 14 quality criteria ($M = 6.76$, $SD = 1.91$, range = 3.50–11.00). The results of the study quality assessment including references are summarized in Table 2.

Effects of Intervention

For the first meta-analysis illustrated in Fig. 2(A), the estimation of standardized mean change (SMC) of *receptive language skills* included ten studies (Dawson et al., 2010; Devescovi et al., 2021; Eikeseth et al., 2002; Eldevik et al., 2006; Fava et al., 2011; Holzinger et al., 2019; Reed et al., 2007; Sinai-Gavrilov et al., 2020; Stanislaw et al., 2020; Vivanti et al., 2014). ABA/NDBI-based interventions revealed a large effect size for receptive language skills ($SMC = 0.74$, 95% CI [0.49, 0.99], 95% PI [0.43, 1.05]). For the second meta-analysis depicted in Fig. 2(B), the estimation of SMC of *expressive language skills* comprised ten studies (Dawson et al., 2010; Devescovi et al., 2021; Eikeseth et al., 2002; Eldevik et al., 2006; Gengoux et al., 2019; Holzinger et al., 2019; Schreibman & Stahmer, 2014; Sinai-Gavrilov et al., 2020; Stanislaw et al., 2020; Vivanti et al., 2014). ABA/NDBI-based interventions revealed a moderate effect size for expressive language ($SMC = 0.48$, 95% CI [−0.08, 1.04], 95% PI [−1.18, 2.14]).

For the third meta-analysis demonstrated in Fig. 2(C), the estimation of SMC *adaptive behavior communication* contained 20 studies (Bejarano-Martin et al., 2022; Dawson et al., 2010; Devescovi et al., 2021; Eikeseth et al., 2002, 2012; Eldevik et al., 2006, 2012; Fava et al., 2011; Gengoux et al., 2019; Grindle et al., 2012; Peters-Scheffer et al., 2010; Reed et al., 2007; Remington et al., 2007; Schreibman & Stahmer, 2014; Sinai-Gavrilov et al., 2020; Stadnick et al., 2015; Stahmer et al., 2020; Stanislaw et al., 2020; Vivanti et al., 2014; Waters et al., 2020). ABA/NDBI-based interventions revealed a moderate effect size for adaptive behavior communication ($SMC = 0.63$, 95% CI [0.29, 0.98], 95% PI [−0.75, 2.02]).

For the fourth meta-analysis presented in Fig. 2(D), the estimation of SMC *adaptive behavior daily living* involved 16 studies (Dawson et al., 2010; Devescovi et al., 2021; Eikeseth et al., 2002, 2012; Eldevik et al., 2006, 2012; Fava et al., 2011; Grindle et al., 2012; Holzinger et al., 2019; Peters-Scheffer et al., 2010; Reed et al., 2007; Remington et al., 2007; Sinai-Gavrilov et al., 2020; Stanislaw et al., 2020; Vivanti et al., 2014; Waters et al., 2020). Interventions based on ABA/NDBI demonstrated a moderate effect size in the domain of adaptive behavior related to daily living ($SMC = 0.49$, 95% CI [0.16, 0.81], 95% PI [−0.64, 1.61]).

For the fifth meta-analysis illustrated in Fig. 2(E), the estimation of SMC *adaptive behavior socialization* consisted of 18 studies (Bejarano-Martin et al., 2022; Dawson et al., 2010; Devescovi et al., 2021; Eikeseth et al., 2002, 2012; Eldevik et al., 2006, 2012; Fava et al., 2011; Grindle et al., 2012; Peters-Scheffer et al., 2010; Reed et al., 2007; Remington et al., 2007; Sinai-Gavrilov et al., 2020; Stadnick et al., 2015; Stahmer et al., 2020; Stanislaw et al., 2020; Vivanti et al., 2014; Waters et al., 2020). ABA/NDBI-based interventions revealed a moderate effect size for adaptive behavior daily living adaptive behavior socialization ($SMC = 0.53$, 95% CI [0.25, 0.81], 95% PI [−0.48, 1.53]).

For the sixth meta-analysis displayed in Fig. 2(F), the estimation of SMC of *adaptive behavior motor skills* included 8 studies (Dawson et al., 2010; Eikeseth et al., 2012; Fava et al., 2011; Reed et al., 2007; Remington et al., 2007; Sinai-Gavrilov et al., 2020; Stanislaw et al., 2020; Vivanti et al., 2014). Interventions based on ABA/NDBI demonstrated a small effect size in the domain of adaptive behavior motor

Table 2 Study Quality Assessment

	Was study pre-registered?	Was sample size pre-justified?	Recruitment process and inclusion/exclusion criteria explained?	Random treatment assignment?	Assessment of baseline IQ and other characteristics?	Intervention explained?	Treatment fidelity/adherence monitored?	Did treatment provider receive supervision?	Validated outcome measures?	Blinded assessors to treatment assignment?	Parent-outcome variables reported?	Number of dropouts described?	Parents` perspectives on treatment acceptability and satisfaction assessed?	Follow-up assessments?
Sheinkopf & Siegel (1998)	-	-	P	-	+	+	-	U	+	P	-	U	-	-
Eikeseth et al. (2002)	-	-	+	-	+	+	-	+	+	+	-	+	-	+ (*)
Eldevik et al. (2006)	-	-	+	-	+	+	P (3)	+	+	U	-	U	-	-
Reed et al. (2007)	-	+	+	-	+	+	-	P	+	-	-	+	-	-
Remington et al. (2007)	-	-	+	-	+	+	P	P	+	P	+	-	-	+ (**)
Dawson et al. (2010)	+	-	+	+	+	+	+ (1)	+	+	+	-	+	-	+ (***)
Peters-Scheffer et al. (2010)	-	-	+	-	+	+	P (2)	P	+	U	-	No dropout	-	-
Fava et al. (2011)	-	-	+	-	+	+	+ (2)	P	+	+	+	No dropout	-	-
Eldevik et al. (2012)	-	-	P	-	+	+	-	+	+	P	-	No dropout	-	-
Eikeseth et al. (2012)	-	-	+	-	P	+	-	+	+	-	-	+	-	-
Flanagan et al. (2012)	-	-	+	-	P	+	-	U	+	U	-	-	-	-

Table 2 (continued)

	Was study pre-registered?	Was sample size pre-justified?	Recruitment process and inclusion/exclusion criteria explained?	Random treatment assignment?	Assessment of baseline IQ and other characteristics?	Intervention explained?	Treatment fidelity/adherence monitored?	Did treatment provider receive supervision?	Validated outcome measures?	Blinded assessors to treatment assignment?	Parent-outcome variables reported?	Number of dropouts described?	Parents` perspectives on treatment acceptability and satisfaction assessed?	Follow-up assessments?
Grindle et al. (2012)	-	-	P	-	+	+	-	+	+	-	-	-	-	-
Schreibman & Stahmer (2014)	-	-	+	+	P	+	+ (2)	-	+	P	+	+	+	-
Vivanti et al. (2014)	-	-	+	-	+	+	+ (2)	-	+	P	-	+	+	-
Stadnick et al. (2015)	-	-	+	-	P	+	P (1)	-	+	U	+	U	-	-
Xu et al. (2017)	-	-	+	+	P	+	+ (1)	-	+	+	-	+	+	-
Gengoux et al. (2019)	+	+	+	+	P	+	+ (2)	+	+	+	-	+	P	-
Holzinger et al. (2019)	-	-	+	-	+	+	+ (1)	P	+	-	+	+	+	-
Stahmer et al. (2019)	-	-	+	-	P	+	+ (1)	-	+	-	+	+	-	-
Sinai-Gavrilov et al. (2020)	-	-	+	-	+	+	+ (1)	P	+	+	-	+	-	-
Stanislaw et al. (2020)	-	-	+	-	+	-	-	P	+	-	-	-	-	-
Waters et al. (2020)	-	-	+	-	+	+	-	P	+	+	-	+	-	-
Devescovi et al. (2021)	-	-	+	-	+	+	P (3)	-	+	-	-	+	+	-

Table 2 (continued)

	Was study pre-registered?	Was sample size pre-justified?	Recruitment process and inclusion/exclusion criteria explained?	Random treatment assignment?	Assessment of baseline IQ and other characteristics?	Intervention explained?	Treatment fidelity/adherence monitored?	Did treatment provider receive supervision?	Validated outcome measures?	Blinded assessors to treatment assignment?	Parent-outcome variables reported?	Number of dropouts described?	Parents` perspectives on treatment acceptability and satisfaction assessed?	Follow-up assessments?
Bejarano-Martín et al. (2022)	-	-	+	-	+	+	-	-	+	+	-	+	+	-
Wang et al. (2023)	-	-	+	+	+	+	-	-	P	+	-	+	-	-

Summary review of the quality assessment consists of 14 criteria developed based on previous research (Des Jarlais et al., 2004; Detsky et al., 1992; Smith et al., 2007). "+" indicates that the study satisfactory met the respective quality criterion, "P" indicates that the study partially met the respective quality criterion, and "-" indicates that the study did not meet the respective quality criterion. "U" indicates unclear.Treatment fidelity monitored: Was intervention implemented as indented and how was is monitored? If studies reported measures on treatment fidelity, they received a "+" = indicates that the study satisfactory met this quality criterion. If studies reported no measures on treatment fidelity, they received a "P" = partial. The way it was monitored was coded with (1) for studies that used a fidelity/adherence scale, (2) for studies that used video ratings and (3) for studies that used supervision.Blinded/independent assessors: In order to avoid examiner bias, were assessors blind to treatment assignment?Supervision: Were therapists who delivered therapy supervised? If studies reported the amount of supervision and the amount of experience of the supervisor, they received a "+" = indicates that the study satisfactory met this quality criterion. If studies did not provide the full information, they received a "P" = partial. Assessment of baseline IQ and other characteristics: If IQ was missing studies received "P".Follow-up assessments: Was there a post-treatment assessment to investigate that effects maintained/were long-term (after a period of time after the intervention was completed still maintained)? References for follow-up assessments: * (Eikeseth et al., 2007), ** (Kovshoff et al., 2011), *** (Estes et al., 2015).

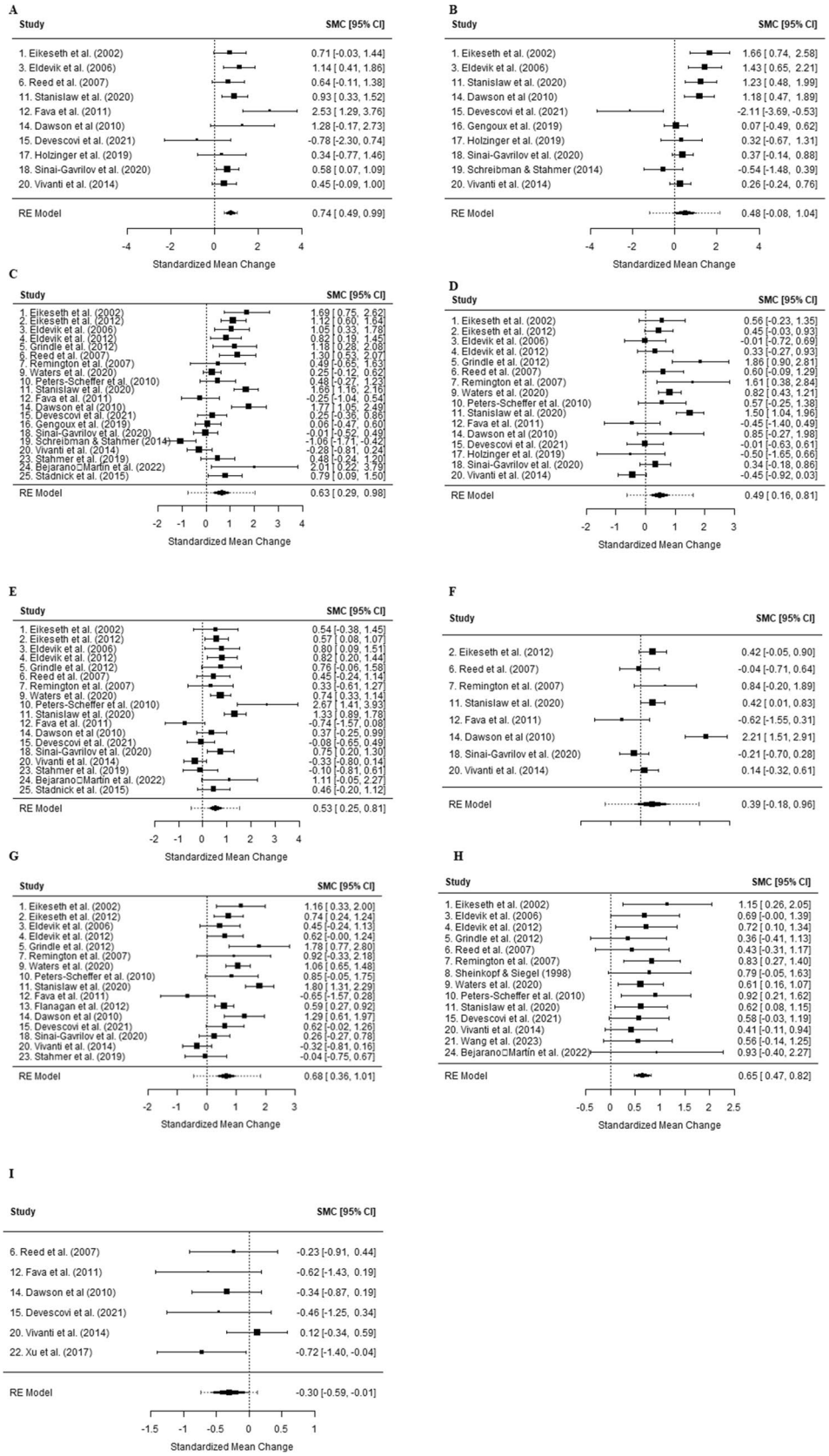


Fig. 2 Meta-analysis forest plots for (**A**) receptive language, (**B**) expressive language, (**C**) adaptive behavior communication, (**D**) adaptive behavior daily living, (**E**) adaptive behavior socialization, (**F**) adaptive behavior motor, (**G**) adaptive behavior composite, (**H**) cognitive skills, and (**I**) reduction in symptoms of ASD. *SMC* standardized mean change, *CI* confidence interval, *RE Model* random effects model

skills (*SMC* = 0.39, 95% CI [−0.18, 0.96], 95% PI [−1.19, 1.97]).

For the seventh meta-analysis illustrated in Fig. 2(G), the estimation of SMC of *adaptive behavior composite* (a composite of the communication, daily living skills, socialization, and motor domains) contained 16 studies (Dawson et al., 2010; Devescovi et al., 2021; Eikeseth et al., 2002, 2012; Eldevik et al., 2006, 2012; Fava et al., 2011; Flanagan et al., 2012; Grindle et al., 2012; Peters-Scheffer et al., 2010; Remington et al., 2007; Sinai-Gavrilov et al., 2020; Stahmer et al., 2020; Stanislaw et al., 2020; Vivanti et al., 2014; Waters et al., 2020). ABA/NDBI-based interventions revealed a moderate effect size for adaptive behavior composite (*SMC* = 0.68, 95% CI [0.36, 1.01], 95% PI [−0.46, 1.82]).

For the eighth meta-analysis illustrated in Fig. 2(H), the estimation of SMC of *cognitive skills* comprised 14 studies (Bejarano-Martin et al., 2022; Devescovi et al., 2021; Eikeseth et al., 2002; Eldevik et al., 2006, 2012; Grindle et al., 2012; Peters-Scheffer et al., 2010; Reed et al., 2007; Remington et al., 2007; Sheinkopf & Siegel, 1998; Stanislaw et al., 2020; Vivanti et al., 2014; Wang et al., 2023; Waters et al., 2020). ABA/NDBI-based interventions revealed a moderate effect size for cognitive skills (*SMC* = 0.65, 95% CI [0.47, 0.82], 95% PI [0.47, 0.82]). For the final meta-analysis depicted in Fig. 2(I), the estimation of SMC of *reductions in symptoms of ASD* involved six studies (Dawson et al., 2010; Devescovi et al., 2021; Fava et al., 2011; Reed et al., 2007; Vivanti et al., 2014; Xu et al., 2018). Interventions based on ABA/NDBI demonstrated a small effect size in the domain of improvement of autism symptom severity (*SMC* = −0.30, 95% CI [−0.59, −0.01], 95% PI [−0.74, 0.13]).

Visual inspection of the funnel plots did reveal some evidence of publication bias regarding expressive language, communication-specific adaptive behavior, and autism symptom severity (Sterne & Egger, 2001; see Fig. 3). However, other reasons for the depicted asymmetry, must be considered, too (e.g., lower methodological quality of smaller studies).

Meta-Regression

Across five (moderators) times nine (outcomes) = 45 univariate meta-regressions, three moderators for three child outcomes emerged: First, ABA/NDBI was more effective in improving adaptive behavior in daily living if children received a higher treatment dose ($\beta = 31.74$, 95% CI [10.69, 52.78], $p < 0.01$) and longer treatment duration ($\beta = 77.33$, 95% CI [27.38, 127.27], $p < 0.01$). Second, ABA/NDBI was more effective in enhancing adaptive motor skills if children started therapy at a younger age ($\beta = -7.28$ 95% CI [−12.77, −1.79], $p < 0.01$). Finally, ABA/NDBI was more effective in improving the adaptive behavior composite score if children received a higher treatment dose ($\beta = 30.37$, 95% CI [9.28, 51.46], $p < 0.01$) and longer treatment duration ($\beta = 82.62$, 95% CI [40.10, 125.15], $p < 0.01$). Coefficients including confidents intervals for meta-regression were multiplied by three. The other variables did not show any moderating effect.

Discussion

This study conducted a meta-analytical examination of the effectiveness of ABA- and NDBI-based interventions in improving communication, cognitive, and adaptive skills as well as reducing challenging symptoms in children identified on the autism spectrum. Moreover, this study also examined to what extent potential moderator variables additionally enhance treatment improvements. Twenty-five studies meeting the inclusion criteria were identified. Effect-size estimation was limited to pre-post control-group designs. A study quality assessment was conducted because the quality of the results of a meta-analysis depends on the quality of the primary studies. Although this quality assessment did not influence the statistical analysis, it reveals strengths and weaknesses of the included studies, suggesting desirable adjustments for future research. The quality assessment revealed the following pattern: While details regarding the recruitment process, the intervention, validated outcome measures and baseline characteristics were well described, criteria like preregistration, randomization and follow-up assessments were seldom realized. Further, more studies with control-groups that investigate long-term benefits of ABA-based interventions designs are needed. Parental outcomes as well as their perspective on the intervention were not commonly reported. In many cases, treatment fidelity—defined as the degree to which a psychological intervention is delivered as intended (Prowse & Nagel, 2015)—was either not formally assessed or inadequately described. Similarly, supervision, which can enhance treatment fidelity (Prowse & Nagel, 2015), was often insufficiently detailed. Studies rarely assessed treatment fidelity and supervision together, instead addressing them as separate concepts. Without these assessments, it is challenging to determine whether a child's lack of progress is due to suboptimal implementation, poor alignment with the child's needs, or both. ABA/NDBI-based interventions revealed a large effect size for receptive language, a moderate effect size for adaptive behavior in communication, daily living, socialization, and the overall composite score, a moderate effect size for cognitive skills, and a small effect for reductions of ASD-specific challenging symptoms. Our

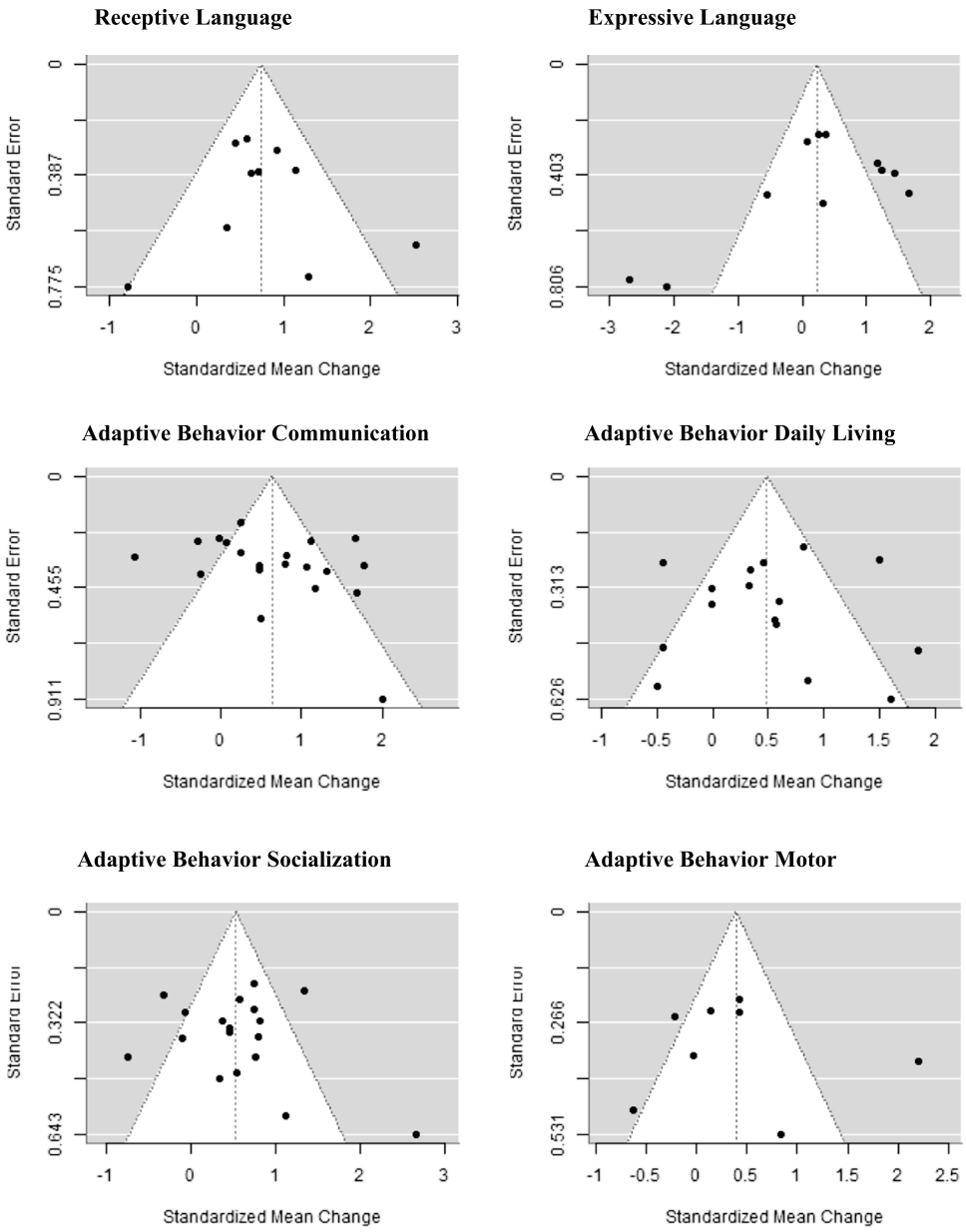
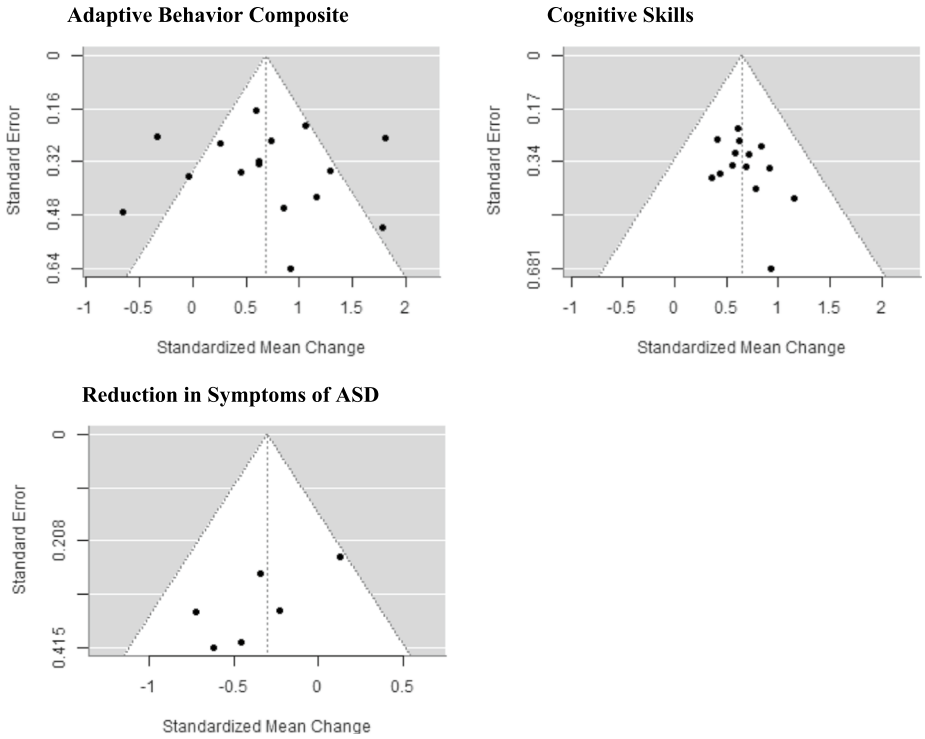


Fig. 3 Funnel Plots for each outcome

findings align with previous systematic reviews and meta-analyses, which reported effect size estimations based on control-group designs and demonstrated positive effects for interventions grounded in ABA/NDBI (Crank et al., 2021; Eldevik et al., 2009; Peters-Scheffer et al., 2011; Reichow et al., 2012; Sandbanket al., 2020a; Tiede & Walton, 2019; Yu et al., 2020). We decided against a comparison of ABA and NDBI studies since any differences would have been only observational and would otherwise require confirmatory studies. A recent study discusses competencies for implementing NDBIs with young children on the autism spectrum and other social communication challenges (Ingersoll et al., 2023). The authors discuss the necessity for providers to understand typical development in social communication skills. Providers are also required to possess expertise in setting goals and monitoring the progress of the child. During the COVID-19 pandemic and for service provision in rural areas, many providers utilized telehealth to deliver services (Klee et al., 2023). Telehealth is defined as the treatment of health-related conditions using communication technology (Ferguson et al., 2019). A recent survey study reported that families of autistic children found benefits in ABA services provided via telehealth during the COVID-19 pandemic (Nohelty et al., 2023). Telehealth-based therapy may also be a promising alternative for families of children on the autism spectrum in rural areas lacking access to healthcare providers

Fig. 3 (continued)



(Guðmundsdóttir et al., 2017). Preliminary meta-analytic results suggest that ABA delivered via telehealth may be a promising and cost-effective way to close existing treatment gaps (Halter et al., 2024). However, further research is needed to demonstrate its effectiveness.

As expected, our meta-regression analysis revealed that ABA-based interventions were more effective in improving adaptive behaviors if children received a higher treatment dose and longer treatment duration. For motor skills in specific, children seemed to benefit from an early onset of ABA/NDBI-based interventions. Although overall our meta-analysis did not reveal a significant effect on motor skills, this potential effect from early onset was evident in the meta-analytical regression. Potentially, this finding can be attributed to a single study investigating very young children and reporting large intervention effects (Dawson et al., 2010). Accordingly, our found intervention onset effect should not be overinterpreted at this point. Still, since well-developed motor skills seem to enable children on the autism spectrum to participate better in social interaction and are positively related to their adaptive behavior (Colombo-Dougovito & Block, 2019; MacDonald et al., 2013), our finding can serve as an interesting impetus for future research. In our meta-analytical regression analyses, it did not seem to play a role whether the therapist received supervision. This is potentially explainable by the fact that most therapists in the included study sample actually received supervision, which can also be considered as an important component of quality standards in interventions.

Limitations and Future Directions

Upon visual inspection of the funnel plots, evidence of publication bias was observed for expressive language, autism symptom severity, and adaptive behavior in communication, whereas no bias was detected for the other analyzed outcomes. This suggests a potential tendency to selectively publish significant outcome variables. As mentioned, only about a third of studies included in our meta-analysis assessed parents'perspectives on treatment acceptability and satisfaction regarding their child's treatment outcomes. It is important to highlight the considerable variety and sometimes imprecise descriptions of control groups assessed in this meta-analysis. Interestingly, ABA-based interventions proved effective in enhancing the receptive language skills but not in improving the expressive language skills in children. This emphasizes the need for a separate analysis of expressive and receptive language skills in future studies. Furthermore, ABA showed no effectiveness in enhancing the motor skills of children. As ABA typically does not specifically target this area (Lovaas, 1987; Schreibman et al., 2015), a combination with motor training programs might prove beneficial (Colombo-Dougovito & Block, 2015). In future clinical research, the measurement of ASD-specific challenging symptom reduction should be supplemented by determining if a change is clinically significant. Clinical significance refers to the importance of the effect of an intervention and whether the intervention makes a real

(i.e., noticeable, practical) difference in everyday life for the patient or for others with whom the patient interact (Kazdin, 1999). Clinically significant change is not restricted to changes in symptoms but includes functioning in everyday life, quality of life, and subjective judgments (Kazdin, 1999). Furthermore, future meta-analyses may also include additional moderators such as ASD-specific challenging symptom severity at baseline as well as co-occurring psychopathology. In our study sample only one study reported co-occurring psychopathologies (Fava et al., 2011). Co-occurring psychopathologies such as attention deficit hyperactivity disorder or sleeping disorders, are highly prevalent in children on the autism spectrum (Reiersen & Todd, 2008; Williams et al., 2004). Given their potential impact on treatment outcomes, it is advisable to include assessments of these conditions as part of baseline measures in treatment studies. Additionally, it's worth noting that only a limited number of studies included in our meta-analysis reported parental outcomes, such as parenting stress. Research findings show a significant correlation between parenting stress and psychopathological symptoms in parents, highlighting its impact on parental mental well-being (Mutschler Collins et al., 2024). Notably, interventions aimed at equipping parents with skills to enhance communication in their children on the autism spectrum have shown promising results: Studies have demonstrated a reduction in parenting stress (Koegel et al., 1996) and an increase in parental self-efficacy following participation in such programs (Feldman & Werner, 2002; Ingersoll et al., 2016). Assessing parenting stress levels has been advocated as a crucial variable in appraising intervention efficacy in early treatment for children on the autism spectrum (Baker-Ericzén et al., 2005; Lessenberry & Rehfeldt, 2004). Finally, as Growth Scale Values were not consistently reported across the studies included in our meta-analysis, we relied on the most commonly reported metrics to ensure comparability. However, future research would benefit from using Growth Scale Values to enhance sensitivity in measuring changes in pediatric populations with neurological or neurodevelopmental disorders, such as children with ASD (Eisengart et al., 2022).

Conclusion

Employing meta-analytic methods, this research investigated the effectiveness of ABA-based interventions, including NDBIs, in enhancing communication, cognitive and adaptive skills and reducing challenging characteristics among children identified on the autism spectrum. Compared to control-groups, ABA-based interventions revealed a large effect size for receptive language skills, a moderate effect sizes for adaptive behavior and cognitive skills, and a small effect size for the reduction of challenging autism spectrum traits. This meta-analysis contributes to the expanding body of evidence supporting ABA/NDBI-based treatments, with a particular focus on key areas such as language, cognitive, and adaptive skills. Moreover, our meta-regression revealed that ABA-based interventions with greater treatment dose and duration yielded greater improvements in adaptive behaviors.

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Declarations

Ethics Approval This is a meta-analysis, no ethics approval was required.

Consent to Participate Not applicable, the present research was a meta-analysis and the authors did not have contact with participants

Competing interests The authors declare no competing interests.

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References

American Psychiatric Association. (1994). *Diagnostic and statistical manual of mental disorders* (4th ed.). https://psychiatryonline.org/doi/book/https://doi.org/10.1176/appi.books.9780890420614.dsm-iv

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). https://doi/book/https://doi.org/10.1176/appi.books.9780890425596

Baker-Ericzén, M. J., Brookman-Frazee, L., & Stahmer, A. (2005). Stress levels and adaptability in parents of toddlers with and without autism spectrum disorders. *Research and Practice for Persons with Severe Disabilities, 30*(4), 194–204. https://doi.org/10.2511/rpsd.30.4.194

Bayley, N. (1993). *Bayley Scales of Infant Development* (2nd ed.). The Psychological Corporation.

Bejarano-Martin, A., Canal-Bedia, R., Magan-Maganto, M., Hernandez Fabian, A., Calvarro Castaneda, A. L., Manso de Dios, S., Malmierca Garcia, P., Diez Villoria, E., Jenaro Rio, C., & Posada de la Paz, M. (2022). Effect of a focused social and communication intervention on preterm children with ASD: A pilot study.

Journal of Autism and Developmental Disorders, 52(4), 1725–1740. https://doi.org/10.1007/s10803-021-05068-8

Brownell, R. (2000a). *Expressive One-Word Picture Vocabulary Test: Manual*. Academic Therapy Publications.

Brownell, R. (2000b). *Receptive One-Word Picture Vocabulary Test: Manual*. Academic Therapy Publications.

Bruinsma, Y. E., Minjarez, M. B., Schreibman, L., & Stahmer, A. C. (2020). *Naturalistic developmental behavioral interventions for autism spectrum disorder*. Brookes Publishing Company. .

Cattell, P. (1960). *Cattell Infant Intelligence Scale*. The Psychological Corporation.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Erlbaum Associates.

Colombo-Dougovito, A. M., & Block, M. E. (2019). Fundamental motor skill interventions for children and adolescents on the autism spectrum: A literature review. *Review Journal of Autism and Developmental Disorders, 6*(2), 159–171. https://doi.org/10.1007/s40489-019-00161-2

Crank, J. E., Sandbank, M., Dunham, K., Crowley, S., Bottema-Beutel, K., Feldman, J., & Woynaroski, T. G. (2021). Understanding the effects of naturalistic developmental behavioral interventions: A project AIM meta-analysis. *Autism Research, 14*(4), 817–834. https://doi.org/10.1002/aur.2471

Dawson, G., Rogers, S., Munson, J., Smith, M., Winter, J., Greenson, J., Donaldson, A., & Varley, J. (2010). Randomized, controlled trial of an intervention for toddlers with autism: The early start denver model. *Pediatrics, 125*(1), e17-23. https://doi.org/10.1542/peds.2009-0958

Des Jarlais, D. C., Lyles, C., Crepaz, N., & Group, T. (2004). Improving the reporting quality of nonrandomized evaluations of behavioral and public health interventions: The TREND statement. *American Journal of Public Health*, *94*(3), 361–366. https://www.ncbi.nlm.nih.gov/pubmed/14998794

Detsky, A. S., Naylor, C. D., O'Rourke, K., McGeer, A. J., & L'Abbé, K. A. (1992). Incorporating variations in the quality of individual randomized trials into meta-analysis. *Journal of Clinical Epidemiology, 45*(3), 255–265. https://doi.org/10.1016/0895-4356(92)90085-2

Devescovi, R., Colonna, V., Dissegna, A., Bresciani, G., Carrozzi, M., & Colombi, C. (2021). Feasibility and outcomes of the early start denver model delivered within the public health system of the friuli venezia giulia italian region. *Brain Sciences*, *11*(9).https://doi.org/10.3390/brainsci11091191

Dunn, L. M., Dunn, L. M., Whetton, C., & Burley, J. (1997). *The British Picture Vocabulary Scale: Manual.* NFER-Nelson.

Eikeseth, S., Klintwall, L., Jahr, E., & Karlsson, P. (2012). Outcome for children with autism receiving early and intensive behavioral intervention in mainstream preschool and kindergarten settings. *Research in Autism Spectrum Disorders, 6*(2), 829–835. https://doi.org/10.1016/j.rasd.2011.09.002

Eikeseth, S., Smith, T., Jahr, E., & Eldevik, S. (2002). Intensive behavioral treatment at school for 4-to 7-year-old children with autism: A 1-year comparison controlled study. *Behavior Modification, 26*(1), 49–68. https://doi.org/10.1177/0145445502026001004

Eikeseth, S., Smith, T., Jahr, E., & Eldevik, S. (2007). Outcome for children with autism who began intensive behavioral treatment between ages 4 and 7: A comparison controlled study. *Behavior Modification, 31*(3), 264–278. https://doi.org/10.1177/0145445506291396

Eisengart, J., Daniel, M., Adams, H., Williams, P., Kuca, B., & Shapiro, E. (2022). Increasing precision in the measurement of change in pediatric neurodegenerative disease. *Molecular Genetics and Metabolism, 137*(1–2), 201–209.

Eldevik, S., Eikeseth, S., Jahr, E., & Smith, T. (2006). Effects of low-intensity behavioral treatment for children with autism and mental retardation. *Journal of Autism and Developmental Disorders, 36*(2), 211–224. https://doi.org/10.1007/s10803-005-0058-x

Eldevik, S., Hastings, R. P., Hughes, J. C., Jahr, E., Eikeseth, S., & Cross, S. (2009). Meta-analysis of early intensive behavioral intervention for children with autism. *Journal of Clinical Child & Adolescent Psychology, 38*(3), 439–450. https://doi.org/10.1080/15374410902851739

Eldevik, S., Hastings, R. P., Jahr, E., & Hughes, J. C. (2012). Outcomes of behavioral intervention for children with autism in mainstream pre-school settings. *Journal of Autism and Developmental Disorders, 42*(2), 210–220. https://doi.org/10.1007/s10803-011-1234-9

Estes, A., Munson, J., Rogers, S. J., Greenson, J., Winter, J., & Dawson, G. (2015). Long-term outcomes of early intervention in 6-year-old children with autism spectrum disorder. *Journal of the American Academy of Child & Adolescent Psychiatry, 54*(7), 580–587. https://doi.org/10.1016/j.jaac.2015.04.005

Fava, L., Strauss, K., Valeri, G., D'Elia, L., Arima, S., & Vicari, S. (2011). The effectiveness of a cross-setting complementary staff- and parent-mediated early intensive behavioral intervention for young children with ASD. *Research in Autism Spectrum Disorders, 5*(4), 1479–1492. https://doi.org/10.1016/j.rasd.2011.02.009

Feldman, M. A., & Werner, S. E. (2002). Collateral effects of behavioral parent training on families of children with developmental disabilities and behavior disorders. *Behavioral Interventions, 17*(2), 75–83. https://doi.org/10.1002/bin.111

Fenson, L., Pethick, S., Renda, C., Cox, J. L., Dale, P. S., & Reznick, J. S. (2000). Short-form versions of the MacArthur communicative development inventories. *Applied Psycholinguistics, 21*(1), 95–116. https://doi.org/10.1017/S0142716400001053

Ferguson, J., Craig, E. A., & Dounavi, K. (2019). Telehealth as a model for providing behaviour analytic interventions to individuals with autism spectrum disorder: A systematic review. *Journal of Autism and Developmental Disorders, 49*(2), 582–616. https://doi.org/10.1007/s10803-018-3724-5

Flanagan, H. E., Perry, A., & Freeman, N. L. (2012). Effectiveness of large-scale community-based Intensive behavioral intervention: A waitlist comparison study exploring outcomes and predictors. *Research in Autism Spectrum Disorders, 6*(2), 673–682. https://doi.org/10.1016/j.rasd.2011.09.011

Gengoux, G. W., Abrams, D. A., Schuck, R., Millan, M. E., Libove, R., Ardel, C. M., Phillips, J. M., Fox, M., Frazier, T. W., & Hardan, A. Y. (2019). A pivotal response treatment package for children with autism spectrum disorder: An RCT. *Pediatrics*, *144*(3). https://doi.org/10.1542/peds.2019-0178

Gilliam, J. E. (1995). *Gilliam Autism Rating Scale: Examiner's Manual*. Pro-ed.

Granpeesheh, D., Dixon, D. R., Tarbox, J., Kaplan, A. M., & Wilke, A. E. (2009). The effects of age and treatment intensity on behavioral intervention outcomes for children with autism spectrum disorders. *Research in Autism Spectrum Disorders, 3*(4), 1014–1022. https://doi.org/10.1016/j.rasd.2009.06.007

Grindle, C. F., Hastings, R. P., Saville, M., Hughes, J. C., Huxley, K., Kovshoff, H., Griffith, G. M., Walker-Jones, E., Devonshire, K., & Remington, B. (2012). Outcomes of a behavioral education model for children with autism in a mainstream school setting. *Behavior Modification, 36*(3), 298–319. https://doi.org/10.1177/0145445512441199

Guðmundsdóttir, K., Sigurðardóttir, Z. G., & Ala'i-Rosales, S. (2017). Evaluation of caregiver training via telecommunication for rural Icelandic children with autism. *Behavioral*

Development Bulletin, 22(1), 215–229. https://doi.org/10.1037/bdb0000040

Halter, F., A.H., M., Lieb, R., & Mutschler Collins, I. (2024, March 19–23). *The efficacy of ABA-based interventions via telehealth for children with autism spectrum disorder: A meta-analysis* [Conference Session]. Wissenschaftliche Tagung Autismus-Spektrum (WTAS), Frankfurt ,Germany. https://wgas-autismus.org/tagung-wtas/

Holzinger, D., Laister, D., Vivanti, G., Barbaresi, W. J., & Fellinger, J. (2019). Feasibility and outcomes of the early start denver model implemented with low intensity in a community setting in Austria. *Journal of Developmental & Behavioral Pediatrics, 40*(5), 354–363. https://doi.org/10.1097/DBP.0000000000000675

Hyman, S. L., Levy, S. E., Myers, S. M., & Council on Children with Disabilities, Section on Developmental and Behavioral Pediatrics. (2020). Identification, evaluation, and management of children with autism spectrum disorder. *Pediatrics, 145*(1). https://doi.org/10.1542/peds.2019-3447

Ingersoll, B., Douglas, S. N., Brodhead, M. T., Barber, A., & Kaczmarek, L. A. (2023). Interdisciplinary competencies for implementing NDBIs with young children with autism and other social communication challenges. *Journal of Early Intervention*, 46(2). https://doi.org/10.1177/10538151231218928

Ingersoll, B., & Dvortcsak, A. (2019). *Teaching social communication to children with autism and other developmental delays (2-book set): The project ImPACT guide to coaching parents and the project ImPACT manual for parents* (2nd ed.). Guilford Publications.

Ingersoll, B., Wainer, A. L., Berger, N. I., Pickard, K. E., & Bonter, N. (2016). Comparison of a self-directed and therapist-assisted telehealth parent-mediated intervention for children with ASD: A pilot RCT. *Journal of Autism and Developmental Disorders, 46*(7), 2275–2284. https://doi.org/10.1007/s10803-016-2755-z

Kazdin, A. E. (1999). The meanings and measurement of clinical significance. *Journal of Consulting and Clinical Psychology, 67*(3), 332–339. https://doi.org/10.1037/0022-006X.67.3.332

Klee, D., Pyne, D., Kroll, J., James, W., & Hirko, K. A. (2023). Rural patient and provider perceptions of telehealth implemented during the COVID-19 pandemic. *BMC Health Services Research, 23*(1), 981. https://doi.org/10.1186/s12913-023-09994-4

Klinger, L. G., Cook, M. L., & Dudley, K. M. (2021). Predictors and moderators of treatment efficacy in children and adolescents with autism spectrum disorder. *Journal of Clinical Child & Adolescent Psychology, 50*(4), 517–524. https://doi.org/10.1080/15374416.2020.1833735

Koegel, R. L., Bimbela, A., & Schreibman, L. (1996). Collateral effects of parent training on family interactions. *Journal of Autism and Developmental Disorders, 26*(3), 347–359. https://doi.org/10.1007/bf02172479

Koegel, R. L., & Koegel, L. K. (2018). *Pivotal response treatment for autism spectrum disorders* (2nd ed.). Brookes Publishing.

Kovshoff, H., Hastings, R. P., & Remington, B. (2011). Two-year outcomes for children with autism after the cessation of early intensive behavioral intervention. *Behavior Modification, 35*(5), 427–450. https://doi.org/10.1177/0145445511405513

Kurita, H. (1985). Infantile autism with speech loss before the age of thirty months. *Journal of the American Academy of Child Psychiatry, 24*(2), 191–196. https://doi.org/10.1016/S0002-7138(09)60447-7

Lessenberry, B. M., & Rehfeldt, R. A. (2004). Evaluating stress levels of parents of children with disabilities. *Exceptional Children, 70*(2), 231–244. https://doi.org/10.1177/001440290407000207

Linstead, E., Dixon, D. R., Hong, E., Burns, C. O., French, R., Novack, M. N., & Granpeesheh, D. (2017). An evaluation of the effects of intensity and duration on outcomes across treatment domains for children with autism spectrum disorder. *Translational Psychiatry, 7*(9). https://doi.org/10.1038/tp.2017.207

Lord, C. (1999). *Autism Diagnostic Observation Schedule (ADOS): Manual*. Western Psychological Services. .

Lord, C., Shulman, C., & DiLavore, P. (2004). Regression and word loss in autistic spectrum disorders. *Journal of Child Psychology and Psychiatry, 45*(5), 936–955. https://doi.org/10.1111/j.1469-7610.2004.t01-1-00287.x

Lovaas, O. I. (1987). Behavioral treatment and normal educational and intellectual functioning in young autistic children. *Journal of Consulting and Clinical Psychology, 55*(1), 3–9.

Lovaas, O. I. (2003). *Teaching individuals with developmental delays: Basic intervention techniques*. Pro-ed.

MacDonald, M., Lord, C., & Ulrich, D. (2013). The relationship of motor skills and adaptive behavior skills in young children with autism spectrum disorders. *Research in Autism Spectrum Disorders, 7*(11), 1383–1390. https://doi.org/10.1016/j.rasd.2013.07.020

Magiati, I., Tay, X. W., & Howlin, P. (2014). Cognitive, language, social and behavioural outcomes in adults with autism spectrum disorders: A systematic review of longitudinal follow-up studies in adulthood. *Clinical Psychology Review, 34*(1), 73–86. https://doi.org/10.1016/j.cpr.2013.11.002

Miranda, A., Berenguer, C., Baixauli, I., & Roselló, B. (2023). Childhood language skills as predictors of social, adaptive and behavior outcomes of adolescents with autism spectrum disorder. *Research in Autism Spectrum Disorders, 103*,. https://doi.org/10.1016/j.rasd.2023.102143

Mitchell, S., Brian, J., Zwaigenbaum, L., Roberts, W., Szatmari, P., Smith, I., & Bryson, S. (2006). Early language and communication development of infants later diagnosed with autism spectrum disorder. *Journal of Developmental & Behavioral Pediatrics, 27*(2), S69–S78. https://doi.org/10.1097/00004703-200604002-00004

Morris, S. B. (2008). Estimating effect sizes from pretest-posttest-control group designs. *Organizational Research Methods, 11*(2), 364–386. https://doi.org/10.1177/1094428106291059

Mullen, E. M. (1995). *Mullen Scales of Early Learning: Manual*. American Guidance Service.

Mutschler Collins, I., Durer, M., Deraita, J., & Meyer, A. H. (2024). *Parents' experiences of raising a child with autism spectrum disorder in switzerland [Manuscript submitted for publication]*. University of Basel.

Nohelty, K., Hahs, A. D., Rodriguez, K. A., Rue, H., Cameron, M. J., & Dixon, D. R. (2023). Assessing the social validity of telehealth-based applied behavior analysis services for autism spectrum disorder. *Behavioral Interventions, 38*(3), 590–610. https://doi.org/10.1002/bin.1938

Osterling, J., & Dawson, G. (1994). Early recognition of children with autism: A study of first birthday home videotapes. *Journal of Autism and Developmental Disorders, 24*(3), 247–257. https://doi.org/10.1007/bf02172225

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hrobjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., . . . Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews [Declaracion PRISMA 2020: Una guia actualizada para la publicacion de revisiones sistematicas]. *Revista Española de Cardiología (English Edition), 74*(9), 790–799. https://doi.org/10.1016/j.rec.2021.07.010

Peters-Scheffer, N., Didden, R., Korzilius, H., & Sturmey, P. (2011). A meta-analytic study on the effectiveness of comprehensive ABA-based early intervention programs for children with autism

spectrum disorders. *Research in Autism Spectrum Disorders, 5*(1), 60–69. https://doi.org/10.1016/j.rasd.2010.03.011

Peters-Scheffer, N., Didden, R., Mulders, M., & Korzilius, H. (2010). Low intensity behavioral treatment supplementing preschool services for young children with autism spectrum disorders and severe to mild intellectual disability. *Research in Developmental Disabilities, 31*(6), 1678–1684. https://doi.org/10.1016/j.ridd.2010.04.008

Prowse, P.-T., & Nagel, T. M. (2015). A meta-evaluation: The role of treatment fidelity within psychosocial interventions during the last decade. *African Journal of Psychiatry*, *18*(2), 1000251. https://research.monash.edu/en/publications/a-meta-evaluation-the-role-of-treatment-fidelity-within-psychosoc

Pugliese, C. E., Anthony, L., Strang, J. F., Dudley, K., Wallace, G. L., & Kenworthy, L. (2015). Increasing adaptive behavior skill deficits from childhood to adolescence in autism spectrum disorder: Role of executive function. *Journal of Autism and Developmental Disorders, 45*(6), 1579–1587. https://doi.org/10.1007/s10803-014-2309-1

Reed, P., Osborne, L. A., & Corness, M. (2007). The real-world effectiveness of early teaching interventions for children with autism spectrum disorder. *Exceptional Children, 73*(4), 417–433. https://doi.org/10.1177/001440290707300402

Reichow, B., Steiner, A. M., & Volkmar, F. (2012). Social skills groups for people aged 6 to 21 with autism spectrum disorders (ASD). *Cochrane Database of Systematic Reviews, 2012*(7), CD008511. https://doi.org/10.1002/14651858.CD008511.pub2

Reiersen, A. M., & Todd, R. D. (2008). Co-occurrence of ADHD and autism spectrum disorders: Phenomenology and treatment. *Expert Review of Neurotherapeutics, 8*(4), 657–669. https://doi.org/10.1586/14737175.8.4.657

Remington, B., Hastings, R. P., Kovshoff, H., & degli Espinosa, F., Jahr, E., Brown, T., Alsford, P., Lemaic, M., & Ward, N. (2007). Early intensive behavioral intervention: Outcomes for children with autism and their parents after two years. *American Journal on Mental Retardation, 112*(6), 418–438. https://doi.org/10.1352/0895-8017(2007)112[418:eibiof]2.0.co;2

Reynell, J. K. (1990). *Reynell Developmental Language Scales: Manual*. Nfer-Nelson.

Rogers, S. J., & Dawson, G. (2009). *Early start denver model for young children with autism: Promoting language, learning, and engagement*. Guilford Publications.

Roid, G. H., & Miller, L. J. (1997). *Leiter International Performance Scale-Revised (Leiter-R): Examiner's manual*. Wood Dale, IL: Stoelting, 10.

Sandbank, M., Bottema-Beutel, K., Crowley, S., Cassidy, M., Dunham, K., Feldman, J. I., Crank, J., Albarran, S. A., Raj, S., Mahbub, P., & Woynaroski, T. G. (2020). Project AIM: Autism intervention meta-analysis for studies of young children. *Psychological Bulletin, 146*(1), 1–29. https://doi.org/10.1037/bul0000215

Sandbank, M., Bottema-Beutel, K., Crowley, S., Cassidy, M., Feldman, J. I., Canihuante, M., & Woynaroski, T. (2020). Intervention effects on language in children with autism: A project AIM meta-analysis. *Journal of Speech, Language, and Hearing Research, 63*(5), 1537–1560. https://doi.org/10.1044/2020_JSLHR-19-00167

Schopler, E., Reichler, R. J., Bashford, A., Lansing, M., & Marcus, L. M. (1990). *Individualized Assessment and Treatment for Autistic and Developmentally Disabled Children (Vol. 1): Psychoeducational Profile-Revised (PEP-R).* Pro-ed.

Schopler, E., Reichler, R. J., & Renner, B. R. (2002). *The Childhood Autism Rating Scale (CARS): Manual*. Western Psychological Services.

Schreibman, L., Dawson, G., Stahmer, A. C., Landa, R., Rogers, S. J., McGee, G. G., Kasari, C., Ingersoll, B., Kaiser, A. P., Bruinsma, Y., McNerney, E., Wetherby, A., & Halladay, A. (2015). Naturalistic developmental behavioral interventions: Empirically validated treatments for autism spectrum disorder. *Journal of Autism and Developmental Disorders, 45*(8), 2411–2428. https://doi.org/10.1007/s10803-015-2407-8

Schreibman, L., & Stahmer, A. C. (2014). A randomized trial comparison of the effects of verbal and pictorial naturalistic communication strategies on spoken language for young children with autism. *Journal of Autism and Developmental Disorders, 44*(5), 1244–1251. https://doi.org/10.1007/s10803-013-1972-y

Sheinkopf, S. J., & Siegel, B. (1998). Home-based behavioral treatment of young children with autism. *Journal of Autism and Developmental Disorders*, *28*(1), 15–23. https://www.ncbi.nlm.nih.gov/pubmed/9546298

Sinai-Gavrilov, Y., Gev, T., Mor-Snir, I., Vivanti, G., & Golan, O. (2020). Integrating the early start denver model into Israeli community autism spectrum disorder preschools: Effectiveness and treatment response predictors. *Autism, 24*(8), 2081–2093. https://doi.org/10.1177/1362361320934221

Smith, T., Scahill, L., Dawson, G., Guthrie, D., Lord, C., Odom, S., Rogers, S., & Wagner, A. (2007). Designing research studies on psychosocial interventions in autism. *Journal of Autism and Developmental Disorders, 37*(2), 354–366. https://doi.org/10.1007/s10803-006-0173-3

Snijders, J. T., Tellegen, P., Winkel, M., & Laros, J. (1996). *SON-R 2, 5–7 Snijders-Oomen Niet-verbale Intelligentietest-Revisie* [SON-R 2, 5–7 Snijders-Oomen Non-Verbal Intelligence Test-Revised].Swets & Zeitlinger.

Sparrow, S. S., Cicchetti, D. V., & Balla, D. A. (2005). *Vineland Adaptive Behavior Scales - Second Edition: Manual.* Pearson.

Spineli, L. M., & Pandis, N. (2020). Prediction interval in random-effects meta-analysis. *American Journal of Orthodontics and Dentofacial Orthopedics, 157*(4), 586–588. https://doi.org/10.1016/j.ajodo.2019.12.011

Stadnick, N. A., Stahmer, A., & Brookman-Frazee, L. (2015). Preliminary effectiveness of project ImPACT: A parent-mediated intervention for children with autism spectrum disorder delivered in a community program. *Journal of Autism and Developmental Disorders, 45*(7), 2092–2104. https://doi.org/10.1007/s10803-015-2376-y

Stahmer, A. C., Rieth, S. R., Dickson, K. S., Feder, J., Burgeson, M., Searcy, K., & Brookman-Frazee, L. (2020). Project ImPACT for toddlers: Pilot outcomes of a community adaptation of an intervention for autism risk. *Autism, 24*(3), 617–632. https://doi.org/10.1177/1362361319878080

Stanislaw, H., Howard, J., & Martin, C. (2020). Helping parents choose treatments for young children with autism: A comparison of applied behavior analysis and eclectic treatments. *Journal of the American Association of Nurse Practitioners, 32*(8), 571–578. https://doi.org/10.1097/JXX.0000000000000290

Sterne, J. A., & Egger, M. (2001). Funnel plots for detecting bias in meta-analysis: Guidelines on choice of axis. *Journal of Clinical Epidemiology, 54*(10), 1046–1055. https://doi.org/10.1016/s0895-4356(01)00377-8

Stutsman, R. (1948). *Guide for Administering the Merrill–Palmer Scale of Mental Tests.* Harcourt, Brace & World.

Thorndike, R. L., Hagan, E. P., & Sattler, J. M. (1986). *The Stanford–Binet Intelligence Scale*. Riverside Publishing.

Tiede, G., & Walton, K. M. (2019). Meta-analysis of naturalistic developmental behavioral interventions for young children with autism spectrum disorder. *Autism, 23*(8), 2080–2095. https://doi.org/10.1177/1362361319836371

Uljarevic, M., Billingham, W., Cooper, M. N., Condron, P., & Hardan, A. Y. (2021). Examining effectiveness and predictors of treatment response of pivotal response treatment in autism: An umbrella review and a meta-analysis. *Frontiers in Psychiatry, 12*,. https://doi.org/10.3389/fpsyt.2021.766150

Viechtbauer, W. (2010). Conducting meta-analyses in R with the metafor package. *Journal of Statistical Software*, *36*(3), 1–48. https://doi.org/10.18637/jss.v036.i03

Vivanti, G., Paynter, J., Duncan, E., Fothergill, H., Dissanayake, C., Rogers, S. J., & Victorian, A. T. (2014). Effectiveness and feasibility of the early start denver model implemented in a group-based community childcare setting. *Journal of Autism and Developmental Disorders, 44*(12), 3140–3153. https://doi.org/10.1007/s10803-014-2168-9

Wang, L., Li, S., & Wang, C. (2023). Using pivotal response treatment to improve language functions of autistic children in special schools: A randomized controlled trial. *Journal of Autism and Developmental Disorders, 54*, 2081–2093. https://doi.org/10.1007/s10803-023-05988-7

Wang, Z., Loh, S. C., Tian, J., & Chen, Q. J. (2022). A meta-analysis of the effect of the early start denver model in children with autism spectrum disorder. *International Journal of Developmental Disabilities, 68*(5), 587–597. https://doi.org/10.1080/20473869.2020.1870419

Waters, C. F., Amerine Dickens, M., Thurston, S. W., Lu, X., & Smith, T. (2020). Sustainability of early intensive behavioral intervention for children with autism spectrum disorder in a community setting. *Behavior Modification, 44*(1), 3–26. https://doi.org/10.1177/0145445518786463

Wechsler, D. (1974). *Wechsler Intelligence Scale for Children-Revised: Manual*. Psychological Corporation.

Wechsler, D. (1990). *Wechsler Preschool and Primary Scale of Intelligence (WPPSI): Manual*. Psychological Corporation.

Williams, G. P., Sears, L. L., & Allard, A. M. (2004). Sleep problems in children with autism. *Journal of Sleep Research, 13*(3), 265–268. https://doi.org/10.1111/j.1365-2869.2004.00405.x

World Health Organisation. (2007). *International classification of diseases* (10th ed.). World Health Organisation Geneva.

World Health Organization. (2019). 6A02: Autism spectrum disorder. In *The international classification of diseases (ICD-11)*. https://icd.who.int/browse11/l-m/en#/http://id.who.int/icd/entity/437815624

Xu, Y., Yang, J., Yao, J., Chen, J., Zhuang, X., Wang, W., Zhang, X., & Lee, G. T. (2018). A pilot study of a culturally adapted early intervention for young children with autism spectrum disorders in China. *Journal of Early Intervention, 40*(1), 52–68. https://doi.org/10.1177/1053815117748408

Yu, Q., Li, E., Li, L., & Liang, W. (2020). Efficacy of interventions based on applied behavior analysis for autism spectrum disorder: A meta-analysis. *Psychiatry Investigation*, *17*(5), 432–443. https://doi.org/10.30773/pi.2019.0229

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