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Review Article

Comparing Interventions With Speech-Generating Devices and Other Augmentative and Alternative Communication Modes: A Meta-Analysis

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ABSTRACT

Purpose: Optimal augmentative and alternative communication (AAC) systems for children with complex communication needs depend in part on child characteristics, child preferences, and features of the systems themselves. The purpose of this meta-analysis was to describe and synthesize single case design studies comparing young children's acquisition of communication skills with speech-generating devices (SGDs) and other AAC modes.

Method: A systematic search of published and gray literature was conducted. Data related to study details, rigor, participant characteristics, design information, and outcomes were coded for each study. A random effects multilevel meta-analysis was performed using log response ratios as effect sizes.

Results: Nineteen single case experimental design studies with 66 participants (M_{age} = 4.9 years) met inclusion criteria. All but one study featured requesting as the primary dependent variable. Visual analysis and meta-analysis indicated no differences between use of SGDs and picture exchange for children learning to request. Children demonstrated preferences for and learned to request more successfully with SGDs than with manual sign. Children who preferred picture exchange also learned to request more easily with picture exchange than with SGDs.

Conclusions: Young children with disabilities may be able to request equally well with SGDs and picture exchange systems in structured contexts. More research is needed comparing AAC modes with diverse participants, communication functions, linguistic complexity, and learning contexts.

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Children who cannot meet all their communication needs with speech (i.e., children with complex communication needs [CCN]) are likely to benefit from comprehensive early intervention services that incorporate augmentative and alternative communication (AAC)—systems for communicating that can be used instead of or in addition to speech (Beukelman & Light, 2020; Romski et al., 2015). Extant research has shown that AAC promotes gains in spoken language, improvement in speech intelligibility, reduction in challenging behaviors, and improvement in language comprehension (Beukelman & Light, 2020; Ganz et al., 2014; Romski et al., 2010; Schlosser & Wendt, 2008).

Relative Advantages of AAC Systems

There are advantages and disadvantages to different types of AAC. Unaided systems (e.g., manual sign [MS] language) do not require communicators to acquire or carry anything with them. This marked advantage potentially contributes to speech-language pathologists' frequent recommendation of sign language as AAC for young children who are not speaking (Lorang et al., 2022). Sign language can be less useful when communication partners recognize a limited number of signs and when signs must be adapted to accommodate children's fine motor abilities (Johnston & Coseby, 2012).

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Aided systems ameliorate some disadvantages of using unaided AAC systems because they are more accessible and transparent for most communication partners. The most well-established picture-based aided AAC system is the Picture Exchange Communication System (PECS; Bondy & Frost, 2001). PECS has a well-defined teaching protocol based on the principles of applied behavior analysis. The phases of training progress from requesting by exchanging single symbols for desired items in Phase 1 to answering questions such as, "What do you see?" with short phrases in Phase 6. The effectiveness of PECS interventions for teaching children with autism to request is supported by a substantial body of research, but few studies have targeted functional communication skills beyond requesting (Ganz et al., 2012).

Aided AAC interventions involving speech-generating devices (SGDs) also have research support (Crowe et al., 2021; Ganz et al., 2014; Gevarter & Zamora, 2018). A distinguishing feature of SGDs, in addition to providing speech output, is the capacity for a virtually unlimited range of language content (Light et al., 2019). Compared with picture symbols and static displays, which have limited capacity for language content, SGDs may better support the complex language use required to meet the academic and social needs of school-age children (Arndt & Schuele, 2013). Some researchers have observed that children using SGDs learned to produce multi-symbol utterances more rapidly than children using static communication boards without speech output, although both modes were ultimately effective (Binger et al., 2008; Binger & Light, 2007). Another advantage of SGDs is the variety of access methods available for selecting symbols, including direct selection, eye gaze, and switches with or without scanning (Beukelman & Light, 2020). This range of access methods can accommodate the needs of children with a variety of sensory and motor abilities as well as increase efficiency of communicating. Aided AAC systems (e.g., PECS or SGD) require children and their caregivers to acquire, carry, and maintain the systems (e.g., programming vocabulary; Light et al., 2019). SGDs, in particular, may present a significant burden to families in terms of cost and effort to maintain the device.

Child Characteristics and AAC Selection

Educational professionals and families must consider, among other characteristics, children's *device preferences* and *developing skill repertoires and abilities* when selecting an AAC system (Beukelman & Light, 2020). To measure device preference, researchers typically record the AAC system that a participant selects when multiple systems are available. In a systematic review of literature on measurement of device preferences, van der Meer et al. (2011) found that two thirds of participants (ages 2.8–22 years) demonstrated a degree of preference for SGDs and one third demonstrated a degree of preference for picture exchange (PE) systems. The authors were unable to draw conclusions about the effects of preference on learning to communicate using either type of system. Certainly, participant preference for an AAC system should be a major factor in clinical decision making. Understanding the potential association between device preferences and learning is critical to promoting effective, tailored AAC interventions for young children. Further research on the role of preference in learning and using communication systems is warranted.

Children's *ability profiles* also influence their learning and use of AAC systems. Cognitive ability does not determine readiness for learning AAC more broadly (Kangas & Lloyd, 1988); however, it could be that certain AAC systems are easier to learn for children at different developmental levels. The ways that families and clinicians make decisions related to AAC in practice suggest that cognitive ability is sometimes used as a reason for implementing one AAC system over another (Lorang et al., 2022). Overall, it is important to directly investigate the effect of children's ability profiles on their use of different AAC modes.

A variety of AAC systems are generally effective at supporting the communication of children with CCN. Even so, children with CCN may learn one system more efficiently than others, suggesting a need to directly compare AAC systems to identify the best system for individual learners. Comparative studies of different AAC systems have been synthesized in three previous systematic literature reviews of single case design studies (Aydin & Diken, 2020; Gevarter et al., 2013; Lorah et al., 2021). Gevarter et al. (2013) reviewed 28 studies with participants from 2 to 52 years of age and a variety of ability profiles. The authors concluded that multiple types of AAC systems could be effective for any given person but that aided systems were generally superior to unaided systems in terms of efficiency and participant preference. More recently, two meta-analyses of peer-reviewed studies concluded that SGD and PE conditions produced more consistent and robust effect sizes compared with MS conditions for children up to 14 years old with autism (Aydin & Diken, 2020; Lorah et al., 2021). Overall, the research indicates that children with autism tend to learn to use aided systems to communicate more effectively and efficiently than unaided systems. Recent meta-analyses are limited to samples of children with autism (Aydin & Diken, 2020; Lorah et al., 2021), and several years have passed since Gevarter et al. (2013) conducted their review; therefore, an updated synthesis of research is warranted.

Current Research Synthesis

The purpose of the current systematic literature review and meta-analysis was to investigate the comparative effectiveness and efficiency of SGDs and other AAC systems on young children's communication abilities. The following research questions were addressed: (a) Do young children with CCN learn targeted symbolic communication skills more efficiently using SGDs compared with other types of AAC (e.g., sign language, PE)? (b) Do young children with CCN use symbolic communication with greater complexity (e.g., with more advanced morphology or syntax) in interventions incorporating SGDs compared with other types of AAC? (c) Do outcomes vary depending on dependent variable characteristics (i.e., communication function, linguistic form), child characteristics (i.e., AAC preference, etiology of CCN, cognitive ability), and internal validity of the studies?

Method

Search and Selection of Studies

A systematic search of the literature was conducted to identify studies meeting the following criteria: (a) the article was published in English or Spanish, (b) the study had an experimental or quasi-experimental design, (c) participants were younger than 9 years old (early childhood or early elementary age), (d) participants had CCN, (e) the study included a comparison of an SGD intervention condition with a low-tech AAC intervention condition for each participant, and (f) primary study outcomes were related to language or communication. For single case designs, at least one participant had to meet all criteria. For group designs, the majority of participants or the mean value (e.g., age) had to meet criteria. Four online databases (APA PsycInfo, Linguistics and Language Behavior Abstracts, ERIC, and ProQuest Dissertations & Theses Global) were searched. These databases were selected because they contained research related to behavioral and educational interventions. To minimize publication bias, dissertations and theses were included in the search (King et al., 2020). A summary of the search criteria and detailed search terms are in Table 1.

The first author conducted the initial online database search on February 19, 2021, and an updated search on October 5, 2022. Zotero (Version 5.0) was used to remove duplicate records. The first author and a trained doctoral student independently screened the titles and abstracts of all identified articles using Rayyan online software (Ouzzani et al., 2016). All articles endorsed by at least one reviewer during title and abstract screening were included for full text review. Both reviewers independently reviewed the full text of every remaining article and resolved disagreements via consensus. Finally, the first author conducted searches for additional articles by authors who appeared multiple times among the identified articles (Larah van der Meer, Dean Sutherland, Jeff Sigafoos, and Laurie McLay) and among references lists. Because only one experimental group design study was identified (Gilroy et al., 2018), only single-case design studies were included in the review and meta-analysis.

Data Collection

Study features, rigor, participant characteristics, design information, and outcomes were coded in Research Electronic

Table 1. Criteria and search terms.

Component	Inclusion criteria	Exclusion criteria	Search terms
Participants	Children ages 0–8;11 (years;months) and had complex communication needs	Children 9 years or older and/or typically developing	child*[a]
Primary intervention	Included a speech-generating device or voice output communication aid	Consisted of cochlear implants and/or assistive technology interventions unrelated to communication (e.g., iPad visual schedules)	("speech generating device*" OR "voice output communication aid*" OR SGD* OR VOCA OR VOCAs OR iPad OR dynavox or "prentke romich") NOT "cochlear implant*"[b]
Comparison intervention	Included an AAC system without speech output	Not applicable	compar*[a]
Outcomes	At least one of the following measures of symbolic communication using AAC: (a) rate, (b) complexity	Only spoken language, writing, or literacy outcomes measured	Not applicable
Study design	Experimental designs including single case designs, randomized controlled trials, or quasi-experimental designs	Designs were nonexperimental (e.g., case studies, descriptive analyses, qualitative studies, descriptive texts [e.g., book chapters]), or literature reviews or syntheses	treat* or therap* or train* or teach* or intervention*[b]
Other	Published in English or Spanish	Published in any language other than English or Spanish	Filtered to only return English or Spanish results

Note. The truncation character (*) is used to search for variations of terms (e.g., train* retrieves trainer, training, etc.). AAC = augmentative and alternative communication.

[a]Full text search. [b]Title and abstract search.

Data Capture databases (Harris et al., 2009, 2019). At the study level, coded data included (a) authors, (b) publication year, (c) publication type (e.g., peer-reviewed journal, dissertation), (d) design (e.g., alternating treatments design [ATD]), (e) number of participants, (f) whether authors reported inclusion criteria for participants, and (g) whether authors measured and reported social validity. If there was a discrepancy between the design the authors reported using and the design they described in the methods of their article, coders selected the design the authors described in the methods (rather than what they named the design). For example, a major feature distinguishing ATDs and adapted alternating treatments designs (AATDs) is whether the same behavior set was taught in all compared conditions (i.e., ATDs) or separate behavior sets were taught in each condition (i.e., AATDs; Wolery et al., 2018). For these studies, the behavior sets were the symbols (i.e., words, phrases) produced via the AAC system. When authors reported use of an ATD with different symbol sets in each condition, the design was coded an AATD. At the participant level, coded data included (a) participant characteristics (e.g., age, abilities, race/ethnicity, home languages), (b) intervention conditions (e.g., AAC types and technologies, dosage, instructional approach, setting, implementers), (c) dependent variables (e.g., function of communication, linguistic form, metric), and (d) outcomes based on visual analysis. Only participant-level data for participants younger than 9 years old were coded (i.e., at least one participant from each included study).

Unlike group design studies, single-case design studies typically provide raw data in the form of graphs, allowing for effect size calculation for each participant (Pustejovsky & Ferron, 2017). To extract raw data, coders marked all data points on images of graphs using open-source Plot Digitizer software (Huwaldt, 2020), then exported the values of data points to Microsoft Excel for further coding. Each digitized data point was coded with (a) study ID, (b) participant ID, and (c) AAC condition (e.g., SGD, PE, MS). Only intervention phase data were extracted. Baseline phase data were not extracted because they were not available for all designs and were not from a primary comparison condition. Baseline levels were, however, used to evaluate experimental control for each study. Postintervention data were not extracted for meta-analyses, because postintervention phases typically did not include all compared conditions. For interventions with multiple PECS phases, only Phase 1 data were extracted and analyzed. Participants who received interventions using the PECS teaching protocol often progressed through the PECS phases at different rates with each AAC system. Children who advanced more quickly to more difficult phases in one condition could, therefore, demonstrate lower performance in that condition, because responding correctly was more challenging. Including these data in meta-analyses may have yielded misleading findings.

Interrater Agreement

The primary coder (first author), a doctoral student, coded and plot digitized data for all studies. Reliability coding and plot-digitizing was conducted by secondary coders on a randomly selected a sample of six studies (32%), including 18 participants and graphs. Two secondary coders (second author and a trained doctoral student) coded study and participant data. All disagreements were discussed and resolved via consensus. Consensus coded data were used in final analyses. Agreement was calculated on a point-by-point basis, with the number of agreements divided by the total number of agreements plus disagreements to yield a percent of agreement (Ledford et al., 2018). The average point-by-point interrater agreement across study-level and participant-level data was 91.85% (79.31%–97.54%). The secondary coder for plot digitizing data was a trained undergraduate student. Agreements between primary and secondary plot digitized data were counted if the two estimates were within 3% of one another relative to the overall scale of the dependent variable. For example, for a count variable on a y-axis scale of 0–20, the data points scored within 0.6 of one another were counted as agreements. Only primary plot-digitized data were used in final analyses. The cumulative interrater agreement for plot-digitized data was 98.24%.

Internal Validity

Internal validity was evaluated using the Comparative Single-Case Experimental Design Rating System (CSCEDARS; Schlosser et al., 2018). The CSCEDARS is intended for use with single-case experimental designs that compare effectiveness and efficiency of two or more instructional interventions (Schlosser et al., 2018). The Supplemental Material S1 shows our adaptations to the original CSCEDARS items. Items 1–22 address aspects of internal validity pertaining to all designs and participants in a study. Item 23 involves evaluating whether at least one condition was clearly superior to the other compared conditions with a binary yes/no response. Because several designs in the current sample included more than two conditions, Item 23 was excluded from the overall CSCEDARS score. Coders instead visually analyzed the outcomes for each two-way comparison (e.g., SGD vs. PE, SGD vs. MS). Like CSCEDARS Item 23, procedures for visual analysis depended on whether there was a mastery/learning criterion for each condition. For comparisons in studies with mastery/learning criteria, coders analyzed which AAC system was learned more efficiently (i.e., mastered in fewer sessions or trials). For comparisons without criteria, coders analyzed whether children performed better in one condition for at least three consecutive measurement points (Schlosser et al., 2018).

The primary coder (first author) rated CSCEDARS items for all studies, and a secondary coder (second author) rated CSCEDARS items for the randomly selected sample of six studies (32%). All disagreements were resolved via consensus, and consensus codes were used in final analyses. The average point-by-point inter-rater agreement for CSCEDARS data across studies was 90.91% (77.27%–100.00%).

Effect Size Calculation and Meta-Analysis

There is little methodological guidance regarding the selection of appropriate effect size indices within meta-analyses of ATDs or AATDs (Pustejovsky & Ferron, 2017). The log response ratio (LRR) effect size was selected in part for its relative insensitivity to procedural variations across studies, such as the number of sessions per condition (Pustejovsky, 2019). The LRR is appropriate for data on a ratio scale that are unlikely to have zero levels of behavior in the reference condition (Pustejovsky, 2018). The data in the current meta-analysis met these criteria because each condition was an active intervention, and neither was likely to be at or near zero levels during the intervention phase. The LRR has no widely accepted benchmarks, but it can be converted to a percentage difference, which aids interpretation (Pustejovsky, 2018, 2019). One limitation of the LRR is that it assumes there are no increasing or decreasing trends in the data (Pustejovsky, 2018). Trends were likely in the current group of studies, given that the children were acquiring skills over the course of the intervention phase. Visual analysis in conjunction with calculation of effect sizes helped to address this limitation. All statistical analyses were conducted using RStudio Version 1.2.5033 (R Core Team, 2020). LRRs were calculated for each participant using plot digitized data and the batch_calc_ES() function of the "SingleCaseES" package (Pustejovsky et al., 2021).

A random effects multilevel meta-analysis of plot digitized data was conducted for each comparison (i.e., SGD vs. PE, SGD vs. MS) with participant-level data nested within studies (Pustejovsky & Ferron, 2017). The rma.mv() function from the metafor package was used to carry out analyses (Viechtbauer, 2010). First, overall average effect sizes and variance were estimated for each comparison. Next, the distributions of the proposed moderator variables were examined. When the distributions of categorical variables were imbalanced, with most of the studies and effect sizes in a single category (e.g., most participants having the same etiology of CCN), those variables were excluded from moderator analyses. Such imbalances can lead to variable Type 1 error rates (Tipton, 2015). For variables with reasonably balanced distributions, the variables were added to the models one at a time to evaluate the influence of these variables on effect sizes. One study (two participants) involved comparison of SGD and communication board conditions (Tönsing, 2016). Due to the small sample size, findings from this study are reported separately and were excluded from meta-analyses.

Finally, the likelihood of selective reporting and/or publication bias was addressed by visually inspecting funnel plots for evidence of asymmetry and by conducting multilevel meta-analyses to determine whether the standard error predicted effect sizes, thus indicating significant asymmetry of the funnel plots (Rodgers & Pustejovsky, 2021). Sensitivity analyses with and without extreme outliers (> 3 *SD* above or below the mean) were conducted to determine whether outliers skewed findings.

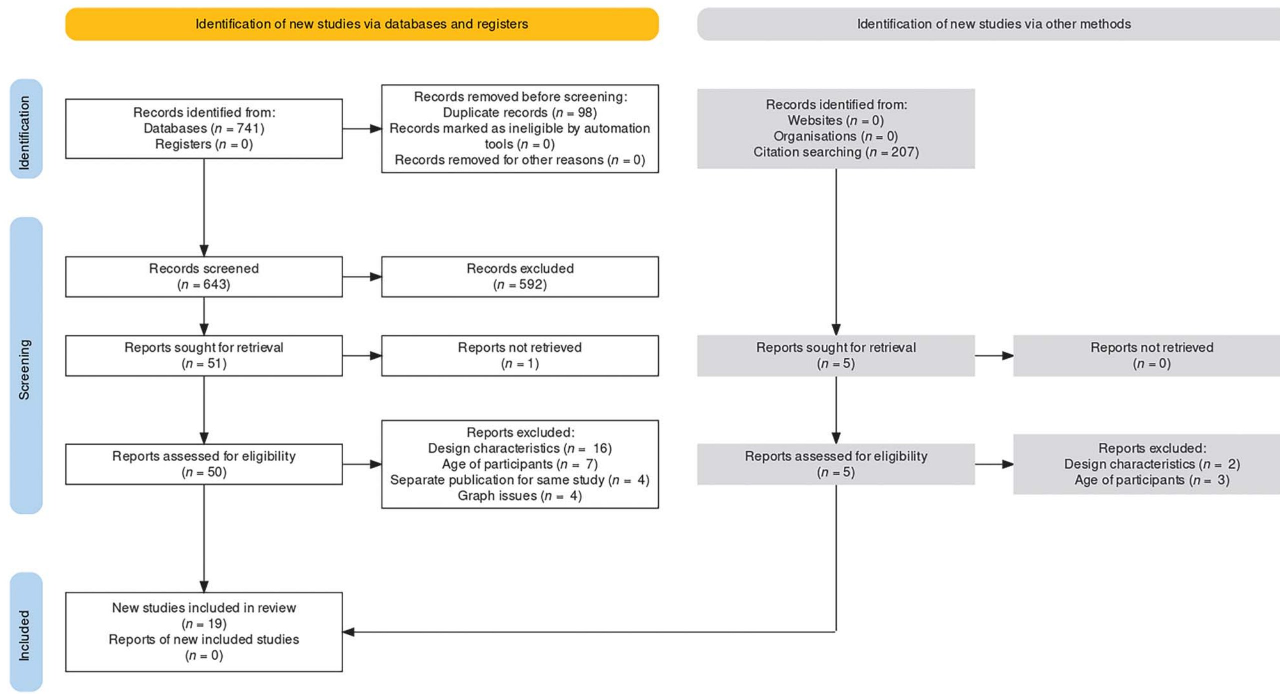
Results

A PRISMA diagram (Haddaway et al., 2021) illustrating each step in the search process and reasons for excluding individual studies is in Figure 1. The online database search yielded 741 records. After removal of 98 duplicates, titles and abstracts of 643 records were screened. Fifty records advanced to full-text review. No additional studies were identified via author searches or citation searches. Studies excluded during coding are in the Supplemental Material S2. After all exclusions, 19 unique studies were coded and analyzed. Full references for included studies are marked with an asterisk in the References list and also listed in Supplemental Material S3. Throughout the remaining sections, numbers of studies are represented by m and numbers of participants are represented by n.

Participant Characteristics

A summary of included participants is in Table 2. There were 66 participants in the target age range across all studies, with 1–9 participants (M = 3.5) per study. Participants ranged in age from 3 to 8 years (M = 4.9). There were 44 boys, 13 girls, and nine children for whom gender was not reported and could not be inferred based on pronoun usage. Race or ethnicity was only reported for nine participants: one Hispanic/Latina, three Samoan, and five White/Caucasian children. Information about the child's primary language, based on explicit reporting or on words the child produced prior to the study, was available for six children. These were Spanish (n = 1), Maltese (n = 1), Setswana (n = 2), and English (n = 2). The majority of children had a primary diagnosis of an autism spectrum disorder (n = 45), followed by developmental delay (n = 10), visual impairment (n = 3), cerebral palsy (n = 2), Down syndrome (n = 2), speech/language impairment (n = 1), attention-deficit/hyperactivity disorder (n = 1), congenital myotonic dystrophy (n = 1), and arthrogryposis (n = 1). Most children (n = 42) used fewer than 10 spoken words and many (n = 21) used gestures (e.g., pointing,

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram.



giving) to communicate. Scores from formal receptive and expressive language assessments were available for 28 and 37 children, respectively. Fine motor scores were available for 17 participants. Cognitive scores were reported for only eight children.

Study Characteristics

A summary of included study designs is in Table 3. Nineteen studies included single case designs, including both ATDs (*m* = 12) and AATDs (*m* = 7). Seven ATDs and three AATDs were embedded in multiple baseline or multiple probe designs. There were two to four compared conditions across studies. Many studies (*m* = 17, *n* = 59) included a mastery criterion (e.g., 80% accurate responding for three consecutive sessions; van der Meer, Kagohara, et al., 2012) for ending the study or moving to the next phase. Thus, most outcomes represented differences in the child's efficiency of learning in the two contrasting conditions.

All studies included an intervention condition involving use of an SGD. The comparison conditions included a PE system (including studies using PECS; Bondy & Frost, 2001) for 61 participants, manual sign (MS for 29 participants, and a communication board for two participants). SGDs included an iPad and/or iPod Touch (*n* = 50), GoTalk (*n* = 10), Tech/Talk (*n* = 3), Logan ProxTalker (*n* = 2), and a 7-Level Communication Builder (*n* = 1). When the SGD was an iPad or iPod Touch, the software application was usually Proloquo2Go (*n* = 41), followed by SoundingBoard (*n* = 7) and GoTalk Now (*n* = 2). For most participants, intervention was conducted in a one-on-one context (*n* = 54) at their school (*n* = 39) by a researcher (*n* = 47). For seven children, the implementer was described imprecisely as the "instructor," "trainer," or one of several implementers (e.g., a researcher or the child's teacher). Implementers were not well described aside from their role. None of the authors reported the race/ethnicity, gender, or languages spoken by the implementer. The PECS teaching protocol was implemented in six studies (*n* = 19) to teach children to request using both PE and the SGD. Interventions in other studies included teaching strategies such as constant time delay (e.g., Achmadi et al., 2014), graduated guidance (e.g., van der Meer, Kagohara, et al., 2012; van der Meer, Sutherland, et al., 2012), and least-to-most prompting (e.g., Son et al., 2006).

The target behavior for nearly all studies and participants was requesting or manding for preferred items or activities (*m* = 18, *n* = 64). Tönsing (2016) compared children's production of two-word semantic relations (agent-action and attribute-entity) with an SGD versus a communication board. In another study (Boesch et al., 2013b), children's nonverbal social communicative behaviors (eye contact, physical orientation, and smiling) were measured in addition to requesting behaviors. These social communicative behaviors were not included in the meta-analysis because they were not symbolic communication.

Table 2. Overview of participants.

Study	Participants in study	Participants in review	Age range (years)	Genders	Primary diagnoses	Home languages	Races/ ethnicities	Preference reported	Cognitive scores reported
Achmadi et al., 2014	4	4	4–5	4 M	3 ASD, 1 DD	NR	NR	Y	N
Agius & Vance, 2016	3	3	3–4	3 M	3 ASD	English, Maltese	NR	Y	Y
Beck et al., 2008	4	4	Preschool	3 M, 1 F	3 ASD, 1 SLI	NR	White	N	N
Bloh et al., 2020	4	4	3–4	3 F, 1 M	4 VI	NR	NR	N	N
Bock et al., 2005	6	6	4	6 M	6 DD	NR	NR	N	N
Boesch et al., 2013a	3	2	6–7	1 M, 1 F	2 ASD	NR, Spanish	White, Latina	N	N
Caradine, 2021	1	1	8	1 F	1 DS	NR	NR	Y	N
Couper et al., 2014	9	8	4–8	8 M	8 ASD	NR	NR	Y	N
Hill & Flores, 2014	5	3	3–4	2 F, 1 M	2 DD, 1 ASD	NR	NR	N	Y
Lorah et al., 2013	5	5	3–5	5 M	5 ASD	NR	NR	Y	N
Lorah, 2016	7	2	8	1 M, 1 F	2 ASD	NR	NR	Y	N
McLay et al., 2015	4	3	7–8	2 M, 1 F	3 ASD	NR	Pacific Islander	Y	N
McLay et al., 2017	2	1	5	1 M	1 ASD	NR	NR	Y	N
Simms, 2015	12	9	3–6	NR	8 ASD, 1 ADHD	NR	NR	Y	N
Son et al., 2006	3	3	3–5	2 F, 1 M	3 ASD	NR	NR	Y	N
Tönsing, 2016	4	2	6–8	1 M, 1 F	2 CP	Setswana	NR	Y	Y
van der Meer, Didden, et al., 2012	4	1	6	1 M	1 ASD	NR	NR	Y	N
van der Meer, Kagohara, et al., 2012	4	3	5–7	3 M	1 DS, 1 DD, 1 CMD	NR	NR	Y	N
van der Meer, Sutherland, et al., 2012	4	2	4	2 M	2 ASD	NR	NR	Y	N

Note. Age, gender, diagnosis, home language, and race/ethnicity data are only for participants included in the review. M = male; ASD = autism spectrum disorder; DD = developmental delay; NR = not reported; Y = yes; N = no; SLI = specific language impairment; VI = visual impairment; DS = Down syndrome; ADHD = attention-deficit/hyperactivity disorder; CP = cerebral palsy; CMD = congenital myotonic dystrophy.

Table 3. Included studies.

Study[a]	Publication type	Design	Conditions	Target behavior	Metric
Achmadi et al., 2014	Journal	ATD	3	Request	Percent
Agius & Vance, 2016	Journal	AATD with concurrent MBL	2	Request	Percent
Beck et al., 2008	Journal	AATD	2	Request	Percent
Bloh et al., 2020	Journal	ATD with nonconcurrent MBL	2	Request	Percent
Bock et al., 2005	Journal	AATD	2	Request	Percent
Boesch et al., 2013a	Journal	AATD with concurrent MBL	2	Request, social	Count
Caradine, 2021	Dissertation	AATD with concurrent MP	2	Request	Percent
Couper et al., 2014	Journal	ATD with nonconcurrent MBL	3	Request	Percent
Hill & Flores, 2014	Journal	ATD	2	Request	Count
Lorah et al., 2013	Journal	ATD	2	Request	Percent
Lorah, 2016	Journal	ATD	2	Request	Percent
McLay et al., 2015	Journal	ATD with nonconcurrent MP	3	Request	Percent
McLay et al., 2017	Journal	ATD with nonconcurrent MP	3	Request	Percent
Simms, 2015	Dissertation	AATD	2–4	Request	Percent
Son et al., 2006	Journal	ATD	2	Request	Percent
Tönsing, 2016	Journal	AATD	2	2-symbol statement	Count
van der Meer, Didden, et al., 2012	Journal	ATD with concurrent MP	2	Request	Percent
van der Meer, Kagohara, et al., 2012	Journal	ATD with concurrent MP	2	Request	Percent
van der Meer, Sutherland, et al., 2012	Journal	ATD with nonconcurrent MBL	3	Request	Percent

Note. ATD = alternating treatments design; AATD = adapted alternating treatments design; MBL = multiple baseline; MP = multiple probe.
[a]First author, publication year.

Internal Validity

The range of possible scores on the CSCEDARS for each study was 0–22, with higher scores indicating greater internal validity. The scores for the 19 studies in the current review ranged from 8.66 (Simms, 2015) to 17.66 (Simms, 2015). Table 4 displays the total item scores across studies. All study reports included operational definitions of the dependent variables that were the same across conditions (Items 3 and 10). All studies had procedural safeguards against carryover effects (Item 16) because the nature of the experimental comparison conditions made them highly discriminable to participants. In other words, the children were able to tell which condition was occurring because only one AAC modality was available in each condition. Fourth, all the included studies had designs that minimized order effects (Item 17), because there were multiple rapid alternations between the conditions. None of the included studies met the criterion for allocating stimuli/sets to each condition in a concealed manner (Item 21) and only two of seven AATD studies (Beck et al., 2008; Bock et al., 2005) met the criterion for random allocation of stimuli/sets to conditions (Item 20). Additionally, many authors did not report procedural fidelity separately for each condition (Item 7); thus, it was unclear if the level of fidelity was similar across comparison conditions.

Effects on Symbolic Communication

The first two research questions were whether young children with CCN would learn to use symbolic communication more efficiently and with greater complexity with interventions incorporating SGDs over other types of AAC. The third research question was whether effects differed by dependent variable, child, and study characteristics. Visual analysis included outcomes from 57

Table 4. Comparative Single-Case Experimental Design Appraisal Rating System (CSCEDARS; Schlosser et al., 2018) summary scores.

CSCEDARS item category	CSCEDARS item number	Number of studies meeting item criteria
Participants	1	12
Setting	2	14
Dependent variable	3	19
	4	13
	5	5
Independent variable	6	17
	7	6
Baseline	8	5
Participants	9	10
Dependent variable	10	19
	11	13
Independent variable	12	11
Baseline	13	16
	14	14
Carryover effects	15	7
	16	19
Order effects	17	19
	18	16
Instructional sets	19	4.29[a]
	20	2
	21	0
Experimental control	22	7

[a]Reflects sum scores across studies. The item allows for partial credit (0, 0.33, 0.66, 1).

participants; meta-analysis included outcomes from 52 participants. The reasons for exclusion of participants from each analysis are in Supplemental Material S4.

Visual Analysis of Outcomes

Outcomes based on visual analysis are shown in Figure 2. Fifty-two designs included a comparison between an SGD and a PE condition. Many participants learned to use both systems equally efficiently (n = 22), and there were equal numbers of participants with superior outcomes in each condition (n = 14). Twenty-five designs included a comparison between an SGD and an MS condition. Most participants achieved better requesting outcomes with the SGD condition (n = 18). Two participants learned to use MS more effectively or efficiently than SGD, two participants learned the two systems equally well, and three participants did not meet criteria in either the SGD or MS condition. Two participants who met inclusion criteria in the Tönsing (2016) study were taught to formulate two-word phrases using an SGD and a communication board during storybook reading. Participant 3 met the mastery criterion with the communication board but not the SGD; Participant 4 did not reach mastery criterion in either condition.

Post hoc analysis. For 13 children across three studies, correct responses required fully or partially picking up the SGD prior to activating the symbol (Agius & Vance, 2016; Beck et al., 2008; Bock et al., 2005). This requirement was meant to prepare the child for the Phase 2 of the PECS protocol in which the child would be required to carry the device to the communication partner. These data were coded and analyzed to examine whether these procedures influenced outcomes. There was a notable discrepancy. For SGD versus PE comparisons in which children were not required to physically pick up the SGD prior to symbol activation (m = 12, n = 36), outcomes favored the SGD condition for 14 children, the PE condition for eight children, and neither condition for 16 children. For the comparisons in which children *were* required to pick up the SGD, none of the children learned more quickly in the SGD condition. Outcomes favored the PE condition for six children and neither condition for seven children.

Meta-Analysis of Outcomes

Effect sizes are depicted in forest plots in Figures 3 and 4. For the SGD versus PE comparisons (m = 15, n = 49), the average effect size was small and nonsignificant (LRR = −0.20, p = .46). This indicates that across studies and participants, levels of responding for SGD and PE conditions were approximately equal. For the SGD versus MS conditions (m = 7, n = 20), the average effect size was statistically significant (LRR = 2.38, $p < .001$), indicating that requesting outcomes were more than 10 times higher for SGD than for MS conditions. All target behaviors in these meta-analyses were single-symbol requests. This made it impossible to address the second research question regarding complexity of communication via meta-analysis.

Funnel plots are depicted in Figure 5. The standard errors did not significantly predict effect sizes for SGD versus PE comparisons (ß = 1.62, p = .09), indicating that the effect sizes were not significantly asymmetrical. Therefore, the funnel plots and statistical tests did not indicate a high risk of publication bias for SGD versus PE comparisons. Upon visually inspecting funnel plots, there were two outliers (> 3 *SD*s below the mean) among the SGD versus PE effect sizes (Beck et al., 2008, participants Brad and Mitchell). These two effect sizes were excluded in a sensitivity analysis to investigate whether findings changed when the outliers were removed. The average effect size remained small and nonsignificant (LRR = −.03, p = .78).

Figure 2. Visual analysis outcomes. For speech-generating devices (SGD) versus picture exchange (PE) comparisons, 52 participants in 16 studies were visually analyzed. For SGD versus manual sign (MS) comparisons, 25 participants in eight studies were visually analyzed.

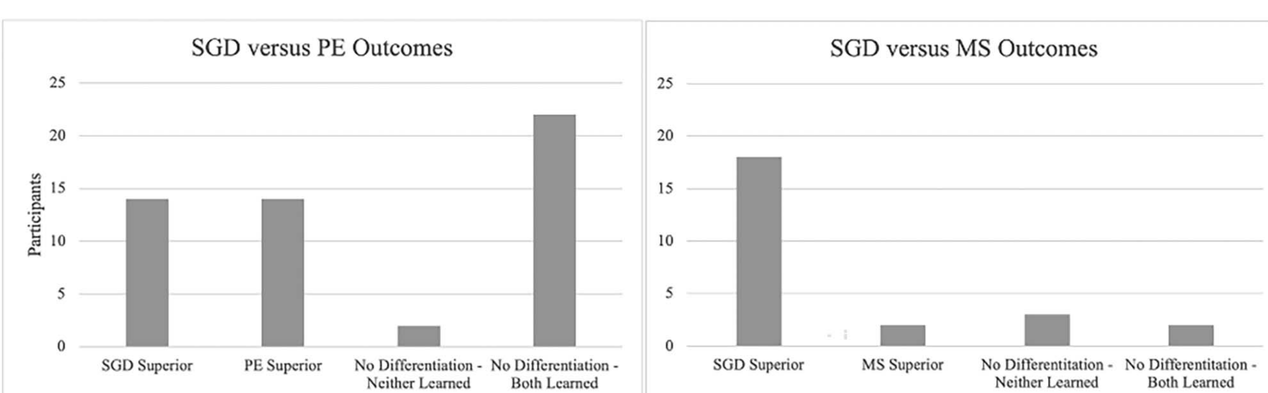
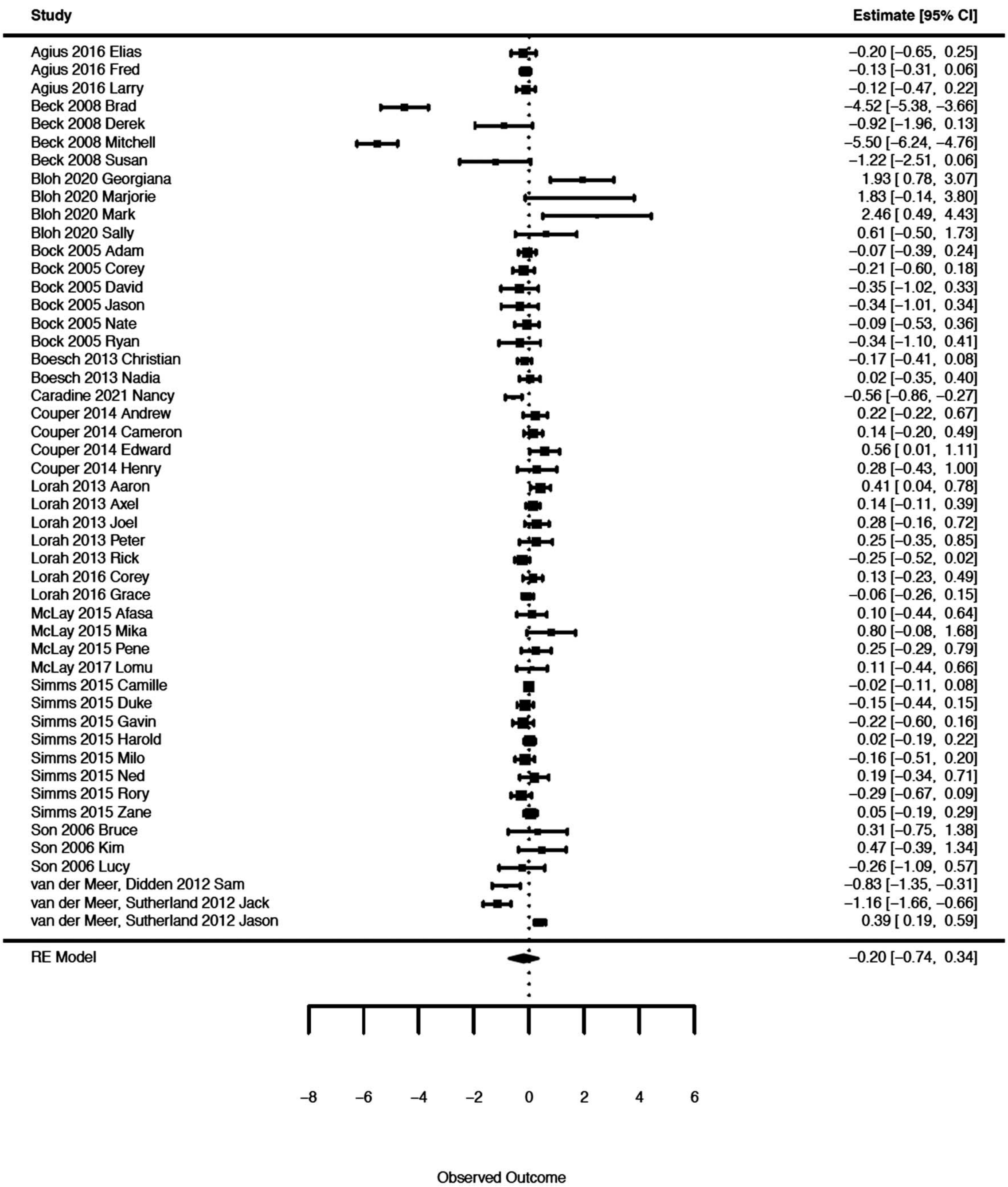
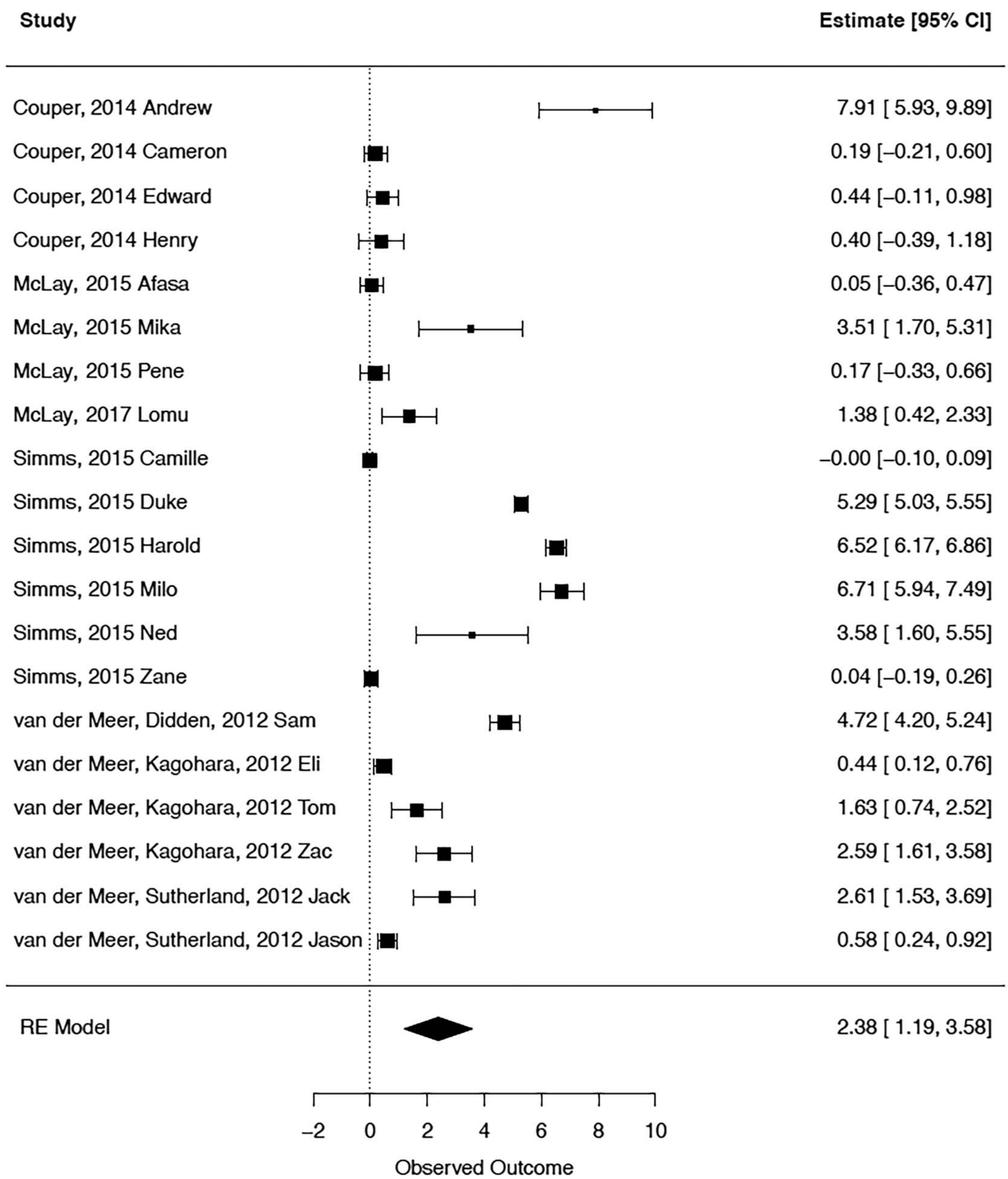


Figure 3. Effect sizes for speech-generating devices versus picture exchange comparisons. RE = random effects.



For SGD versus MS comparisons, many effect sizes were exceedingly small or large relative to the mean and had smaller standard errors than expected. Standard errors significantly predicted effect sizes (ß = 4.31, $p < .05$). This finding indicated that the funnel plots, which depicted several effect sizes outside the expected range, were significantly asymmetrical. This finding is an indicator of potential publication bias, although significant asymmetry could have other causes (Rodgers & Pustejovsky, 2021). The forest plot in Figure 4 indicated that extreme effect sizes tended to vary by participant rather than by study. Thus, there may have been participant characteristics (e.g., fine motor abilities) that influenced children's ability to learn manual sign, with most children either learning it easily or not at all. Because there were no obvious outliers, sensitivity analyses were not conducted for SGD versus MS comparisons.

Figure 4. Effect sizes for speech-generating devices versus manual sign comparisons. RE = random effects.

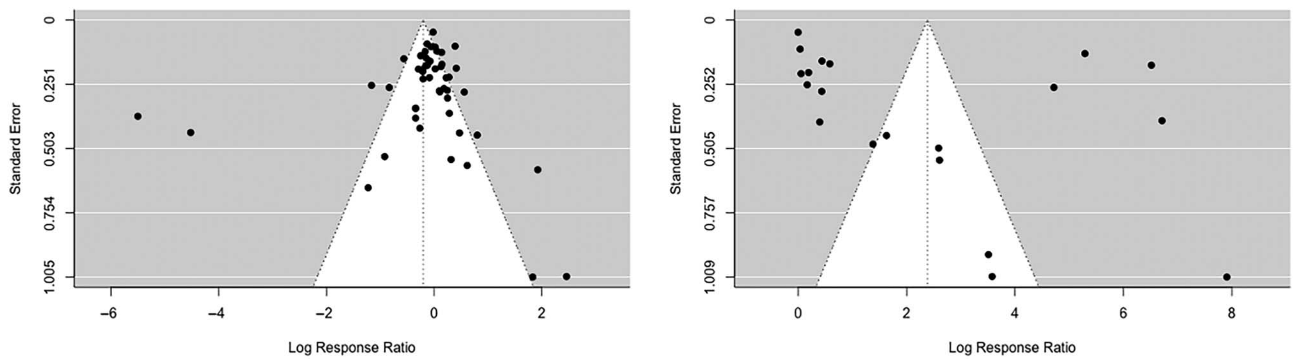


Moderator Analyses

The third research question addressed the potential associations between outcomes and child, study, or variable characteristics. Moderator analyses were planned a priori for (a) dependent variable characteristics (i.e., communication function, linguistic form), (b) child characteristics (i.e., AAC preference, etiology of CCN, cognitive ability), and (c) study internal validity. A post hoc variable was identified while coding studies (i.e., whether the child was required to pick up the SGD). Only two moderator analyses could be completed: child AAC preference and study internal validity scores. There was insufficient variability or reporting of variables across studies in the sample to conduct moderator analyses with the remaining a priori or post hoc variables.

AAC preference. For the SGD versus PE comparisons, preference was not measured for 18 participants, including the two outliers (Beck et al., 2008, participants Brad and Mitchell). Of the participants for whom preference was measured (m = 11, n = 31), all demonstrated a preference for either the SGD (n = 21) or the PE system (n = 10). A multivariate meta-analysis indicated a

Figure 5. Funnel plots for speech-generating devices (SGD) versus picture exchange (PE; left) and manual sign (MS; right). For SGD versus PE comparisons, 49 participants in 15 studies were included in the meta-analysis. For SGD versus MS comparisons, 20 participants in seven studies were included in the meta-analysis.



significant moderating effect of preference on outcomes. The children who preferred the PE system had significantly better outcomes with the PE system (LRR = −0.28, $p <$ .01). The children who preferred the SGD had outcomes that did not differ significantly between the SGD and PE conditions in this small sample (LRR = 0.12, p = .07).

For the SGD versus MS comparisons, preference was measured for 19 out of the 20 participants. Sixteen participants demonstrated a preference for either the SGD (n = 15) or MS (n = 1). The lack of variability in preference across participants did not allow for further analysis. The one participant who demonstrated a preference for MS (Simms, 2015, participant Zane) met mastery criteria more quickly in the SGD and PE conditions than in the MS condition.

Internal validity. The internal validity of the study as measured by the CSCEDARS summed scores (Items 1–22) was not significantly associated with the size of the differences between conditions for the SGD versus PE comparisons (ß = −0.09, p = .38) or the SGD versus MS comparisons (ß = −0.30, p = .21). Results for the SGD versus PE comparisons were unchanged when the two outliers were removed (ß = −0.05, p = .13).

Discussion

The purpose of this systematic review and meta-analysis was to summarize the evidence on the comparative effectiveness and efficiency of SGDs and other AAC systems for young children with CCN learning to communicate symbolically. Nineteen unique studies meeting inclusion criteria were identified, most of which included comparisons of SGDs with PE systems, MS systems, or both. Results from these studies were visually and statistically synthesized. Between SGDs and PE systems, there was no clear advantage of either system for the children learning to request among these studies. In comparison, the SGD was more efficient (i.e., mastered in fewer sessions) than MS for most children learning to request. Nearly all target behaviors in these studies involved single-symbol responses, which did not allow for investigation of comparative effects of AAC systems on complexity of communication.

The findings from the current review are consistent with those from previous reviews with children with autism (Aydin & Diken, 2020; Lorah et al., 2021); however, the current analysis included participants with a greater range of etiologies of CCN. Generally, aided AAC systems (i.e., SGD, PE) appear to be more effective for requesting outcomes than unaided systems (i.e., MS). These findings are also consistent with those from the one group design study identified in the search process (Gilroy et al., 2018) in which both SGD and PECS interventions resulted in increased prompted and unprompted requesting with no interaction between time and AAC type. The replication of these findings across multiple review teams, analytical methods, and specific research questions increases confidence in the conclusions (Gast & Ledford, 2018).

It was also important to consider for whom and under what conditions these effects were relevant. Based on the research identified in the current search, most of the planned moderator analyses could not be performed (i.e., function of communication, linguistic form of communication, child ability profiles, child etiology of CCN). Only participant preference for AAC systems and internal validity of studies were analyzed as moderators. Children who preferred the PE system over the SGD learned to request significantly more efficiently with the PE system (i.e., reached mastery in fewer sessions). Children who preferred the SGD over the PE system did not learn significantly more efficiently with either system, although there was a trend in favor of the SGD (p = .07). It is possible that some children preferred use of PE *because* of their ability to communicate more easily using this system, whereas children who were able to communicate with both systems tended to prefer the high-tech option with more communicative capabilities (e.g., speech output). The relation between children's AAC preference and relative efficiency of learning bears further investigation.

Internal validity was measured using the CSCEDARS tool (Schlosser et al., 2018), adapted for this study. There was a wide range in overall scores across these studies (8.66–17.66 out of a possible 22 points). In general, these study reports contained sufficient descriptive information about participants, variables, and designs. Areas of concern were typically lack of reporting of how stimuli/sets were assigned to each AAC condition and procedural fidelity for each condition. Sufficient measurement of procedural fidelity in each condition is especially important in ATDs and AATDs, because interventionists are required to learn and execute a separate set of procedures for each condition and rapidly alternate conditions across sessions (Wolery et al., 2018). Researchers should take care to measure and report fidelity across conditions to ensure that differences in outcomes are not due to discrepancies in fidelity across conditions. CSCEDARS scores were not significantly associated with outcomes in this relatively small sample; therefore, there was no evidence that stronger outcomes resulted from weak designs, methods, or reporting.

The funnel plots and statistical analyses related to publication bias indicated one main reason for concern. Among the participants who learned to use both the SGD and MS systems, data were significantly asymmetrical (ß = 4.31, $p < .05$) with few effect sizes near the mean (see Figure 5). Based on visual inspection of the forest plot (Figure 4), the variability appeared to occur at the level of the participant rather than the study. In other words, variability may have been due to individual differences rather than publication bias. Future research should explore the influence of additional child variables on learning using different AAC systems.

Strengths and Limitations

There were strengths and limitations to the sample of studies identified in the current review. These studies used ATDs or AATDs, which are appropriate single case designs for answering comparative research questions, and the independent and dependent variables were well defined. Additionally, most studies included baseline conditions that allowed for identification of threats to internal validity. An important limitation to the evidence was established in the post hoc analysis. The intervention procedures in three studies required children to pick up the SGD prior to communicating, despite there being only a small distance between themselves and the communication partner. Outcomes favored the PECS conditions for participants in these studies. The physical movement required to initiate a request via each of the AAC systems is intrinsic to the systems; thus, it is one of the aspects that should be compared rather than controlled. In other words, PECS requires picking up and giving a picture to a communication partner, whereas the speech output of SGDs makes picking up the device unnecessary in many cases. Requiring children to pick up the SGD may have made it unnecessarily inefficient to use and thus more difficult to learn in Phase 1 of the PECS protocol.

A limitation of this review is the lack of investigation other features of the AAC systems that may have influenced their comparative effectiveness or efficiency. For example, SGDs vary in the size and type of displays (Light et al., 2019). The current synthesis did not explore the differences in numbers of symbols available to children in these studies, although some studies with PECS teaching protocols included picture symbol discrimination in later phases of the intervention (Agius & Vance, 2016; Beck et al., 2008; Bock et al., 2005; Boesch et al., 2013b). There are also different types of SGD displays, such as grid versus visual scene displays, that were not coded for this analysis (Ganz et al., 2015; Light et al., 2019). Finally, secondary dependent variables, generalization outcomes, and maintenance outcomes were not analyzed for the current review and meta-analysis, although they were reported in some of the studies. Future systematic reviews should explore comparative effects for AAC systems with different features on a variety of outcome variables.

Generalizability and Implications

The findings from this synthesis may be expected to generalize to a specific population and context: young children with autism or other developmental delays who have CCN when learning to request objects or activities in structured, trial-based teaching contexts. All studies except one (Tönsing, 2016) investigated the differential effects of AAC type on accuracy of requesting as the primary dependent variable. The purposes of communication extend far beyond requesting and include sharing information, forming and cultivating relationships, practicing social etiquette within a given society, and organizing thoughts and ideas (Beukelman & Light, 2020; Light, 1997). Furthermore, competence with various grammatical structures has important implications for academic and social well-being (Arndt & Schuele, 2013). Yet, children and adolescents who use AAC tend to communicate using single-symbol utterances (Binger & Light, 2008). The findings from the current synthesis indicate that SGDs and PE systems are often equally efficient to learn for simple communication tasks (e.g., requesting). Therefore, it may be more efficient to begin intervention with an SGD that would better accommodate growth in grammatical complexity and diverse communicative functions. In the current synthesis, only Tönsing (2016) investigated children's ability to combine words into phrases for commenting using different AAC systems. Tönsing reported that one child learned more easily with the communication board than with the SGD, and another child did not meet learning criteria with either AAC system. Further research is needed to understand the effects of different modes of AAC when children are learning more advanced communication skills.

With these caveats, SGDs and PEs may both be reasonable choices of communication modes for teaching single-symbol requesting to young children with CCN. It is possible that children may benefit from learning to use both SGDs and PE systems. For example, when a child's SGD battery dies while at school, it would be better to have PE as a back-up communication system than for the child to be unable to communicate wants and needs on that day. In contrast, children whose primary communication partners use speech to communicate (i.e., children who are not members of the Deaf community) may learn to request more efficiently with SGDs than with MS.

When making decisions about AAC selection, families and practitioners consider factors beyond children's likelihood of learning a system. Children's preferences for a communication system should be a primary consideration when selecting AAC systems because teaching children to communicate using AAC fundamentally involves empowering them to communicate their choices, ideas, and stories. The current findings suggest that AAC preferences may be related to efficiency of learning in some cases, although the findings should be interpreted with caution given the small sample size. Children may be more motivated to communicate when they find the AAC system to be easy to use or appealing for other reasons (e.g., features such as speech output). Future research could explore this relation further by investigating children's and family's responses to questions about their AAC preferences.

The moderators that could not be explored (i.e., function and complexity of the targeted communication behavior; children's cognitive abilities and etiology of CCN) may also influence practitioner and family decisions. Future studies should involve diverse participants, contexts, and communication functions. Researchers should report participant characteristics that are relevant to communication, such as home language and culture, as well as cognitive and functional abilities. Such research fully describing participants in their cultural and linguistic contexts is necessary for informing policies and the development of technology relevant to minoritized populations (e.g., multilingual AAC systems and interventions).

Conclusions

There are many types of AAC with many different features, all of which should be matched to the communication needs of children with CCN. Understanding the relative effectiveness and efficiency of different types of AAC is important for clinical decision-making. The current systematic review and meta-analysis found that 66 young children who participated in 19 comparative single-case design studies were able to learn to use SGD as efficiently as PE and more efficiently than MS for requesting items. Further research is needed to understand the effects of types of AAC systems on communication for a variety of social purposes, in a variety of linguistic forms, by diverse participants.

Data Availability Statement

The full data sets are available in the Open Science Framework repository, https://osf.io/4jmbn/.

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*Asterisk indicates article included in review.

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