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Augmentative and Alternative Communication Intervention Targets for School-Aged Participants with ASD and ID: A Single-case Systematic Review and Meta-analysis

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Abstract

Objective: This meta-analysis reviews the literature on communication modes, communicative functions, and types of augmentative and alternative communication (AAC) interventions for school-age participants with autism spectrum disorders and/or intellectual disabilities who experience complex communication needs. Considering potential differences related to outcomes that were targeted for intervention could help identify the most effective means of individualizing AAC interventions.

Methods: We performed a systematic literature search using Academic Search Ultimate, ERIC, PsycINFO, Web of Science, and Proquest Dissertations & Theses Global to retrieve research conducted between 1978 and the beginning of 2020. Studies included in the synthesis are (a) in English; (b) has one or more participants with an intellectual delay, developmental disability(ies); (c) reported the results of an augmentative and alternative communication (AAC) intervention to supplement or replace conventional speech for people with complex communication needs; (d) was a SCED; (e) measured social-communicative outcomes. We synthesized results across studies using multi-level meta-analyses of two case-level effect size metrics, Tau and log response ratio. We conducted moderator analyses using meta-regression with robust variance estimation.

Results: Across 114 included studies with 330 participants and 767 effect size, overall Tau effects were moderate, Tau = 0.72, 95% CI [0.67, 0.77], and heterogeneous. For the subset of data series where log response ratio could be estimated, the overall average effect was LRR = 1.86, 95% CI [1.58, 2.13], and effects were highly heterogeneous. There were few statistically significant differences found between moderator categories, which included communication mode, communicative function, and type of AAC implemented.

Conclusions: This meta-analysis highlights the potential differences related to outcomes that were targeted for AAC interventions for individuals with ASD and IDD. AAC intervention has been shown to improve communication outcomes in this population. However, there was a lack of sufficient data to analyze for some potential moderators such as insufficient descriptive information on participant characteristics. This is likely due to the heterogeneity of the participants and implementation factors; however, these factors were frequently underreported by original study authors which disallowed systematic analysis. That said, there is a need for more detailed participant characteristic descriptions in original research reports to support future aggregation across the literature.

Sponsorship: We received funding for the review from the Institute of Education Sciences.

Protocol: The review protocol was registered in the PROSPERO system (CRD42018112428).

Keywords: autism, ASD, intellectual disability, IDD, complex communication needs, minimally- or non-verbal, intervention, behavioral strategies, augmentative and alternative communication

Augmentative and Alternative Communication Intervention Targets for School-Aged Participants with ASD and ID: A Single-case Systematic Review and Meta-analysis

Social-communication deficits are a defining characteristic of autism spectrum disorder (ASD) and/or most intellectual disabilities (ID; Ganz, 2015; Iacono et al., 2016; Logan et al., 2017). Many studies report a range of complex communication needs (CCN) for these individuals (Holyfield et al., 2017; Iacono et al., 2016; Morin et al., 2018). The term CCN applies to individuals who are unable to communicate effectively using speech alone and often benefit from using augmentative and alternative communication (AAC) applications, either temporarily or permanently. For beginning communicators, intervention outcomes often address communicative functions that include *behavioral regulation* (i.e., mands or requesting and protesting). Far less attention has been directed at other communicative functions such as *joint attention* (i.e, directing a partner's attention to a referent) and *social interaction* (a communicative act directing a partner's attention to the person engaging in the communicative act; Ganz, 2015; Ganz, et al., 2017; Logan et al., 2017).

Communication modes (e.g., AAC, speech, gestures) range widely with regard to costs, features, reliability, ease of use, and personal preferences of individuals with CCN and intervention implementers. Thus, it is critical to determine the relative effectiveness, or lack thereof, across modes, to allow for selection decisions. With respect to communicative mode, the existing literature supports the selection of either or a combination of *graphic* or *gestural* communication modes to support *vocal/verbal* mode production (Holyfield et al., 2017; Iacono et al., 2016). Given the varying communication modes used along with heterogeneous participant characteristics, summarizing the evidence and drawing conclusions can be challenging. To date there have been only a handful of studies examining explicit decision rules for determining which AAC mode to emphasize in supplementing vocal/verbal production (see Johnston et al., 2012).

Several reviews, systematic reviews, and meta-analyses have examined the outcomes resulting from the implementation of AAC applications. However, only a few directly examined specific features of communication outcomes (Ganz et al., 2012; 2017), and several of those were systematic reviews but not meta-analyses (Holyfield et al., 2017; Logan et al., 2017). Additionally, prior work shows a great deal of variation in the inclusion criteria for participants (Ganz, 2015; Ganz et al., 2017; Holyfield et al., 2017; Logan et al., 2017; Morin et al., 2018).

Some authors have noted a failure with respect to teaching a full range of complex communicative functions to persons with ASD, ID, and CCN (Ganz, 2015; Ganz et al., 2017; Holyfield et al., 2017; Iacono et al., 2016; Logan et al., 2017; Morin et al., 2018). Requesting, a communicative act that functions as behavior regulation of another person, has a propensity to result in immediate reinforcement, e.g., requesting a tangible item and immediately receiving that item or activity. Thus, requesting allows an interventionist to select initial referents that will be highly motivating. The same is true for protests, where one can ensure that producing a protest allows an individual to avoid an unpleasant activity. In contrast, with communicative functions such as joint attention or social interaction, the interventionist must rely on a social reinforcer. For some learners, social contact with others may not function as a reinforcer. Additionally, requests/protests have an advantage of reinforcer specificity. With persons having severe developmental disabilities, investigators have demonstrated an acquisition advantage when the reinforcer matches the symbol being taught (Litt & Schreibman, 1981; Reichle et al., 1986). As a result, some common manualized interventions introduce additional functions of communication only after mastering behavioral regulation. For example, Picture Exchange Communication Systems (PECS; Bondy & Frost, 1998) starts with teaching requests (behavioral regulation) and much later introduces commenting (joint attention). Finally, deficits of joint-attention and social interaction skills found in people with ASD may factor into the lack of research on this topic (Logan et al., 2017). A small number of reviews have differentiated communicative functions when assessing the effectiveness of AAC interventions for persons with ASD and/or ID who experience a CCN (Ganz, 2015; Ganz et al., 2017; Logan et al., 2017).

Behavior regulation (i.e. requesting, protesting) appears to be the target of intervention most often for individuals with ASD who use AAC (Iacono et al., 2016; Morin et al., 2018), versus functions such as bids for joint attention or social interaction. Further, instruction in behavior regulation was found to be effective for people with ASD in particular, for interventions involving aided or unaided AAC (Holyfield et al., 2017), and for implementation of high-tech AAC (Ganz et al., 2017). One meta-analysis (Ganz et al., 2017) did compare relative effectiveness across communicative functions, although this review focused on high-tech AAC for individuals with ASD and ID who had CCN. Ganz et al. (2017) reported a small, nonsignificant difference between effect sizes for behavior regulation (requesting wants and needs) versus those for joint attention, and a significant difference between behavior regulation versus a social interaction function, with behavior regulation effects calculated as higher than either other function. Due to the small number of data points for social interaction, caution was urged when interpreting these results.

While building behavior regulation skills among individuals with ASD/ID is important; the traditional sparsity of intervention studies addressing other, more socially complex communicative functions represents a limitation in the intervention literature. Many reviews emphasize the lack of outcomes that focus on social interaction and joint-attention as a future research need (Ganz, 2015; Ganz et al., 2017; Holyfield et al., 2017; Iacono et al., 2016; Logan et al., 2017; Morin et al., 2018). These findings suggest that conditions can be established that result in establishing joint attention functions with approximately equal effectiveness. Moreover, prior meta-analyses used outdated effect size metrics, such as Improvement Rate Difference (Ganz et al., 2017; Holyfield et al., 2017) and more information may be gleaned by using metrics that better suit the available data and with a broader literature base.

There is insufficient guidance related to selection of communication modes to emphasize at the outset of intervention with an individual who has not previously depended on or used AAC (Reichle et al., 2019). Parents are sometimes hesitant to choose an AAC application due to fears that their children will be less motivated to develop spoken language (Donato et al., 2018; Moorcroft et al., 2019). Numerous authors have reported these fears to be unfounded (Donato et al., 2018; Johnston et al., 2012; Walters et al., 2021). However, it is important to know whether and how prior experience with AAC has an impact on social-communication outcomes for this population to better inform future treatment decisions. In a majority of studies examined in a recent meta-analysis (Ganz et al., submitted for review) little to no rationale was provided for the augmentative communication modes selected for implementation.

Few prior reviews and meta-analyses have conducted moderator analyses to evaluate the relative effectiveness of types of AAC modes with individuals with ASD and/or ID. Aided AAC was found to be more effective for preschoolers than for older individuals (Ganz et al., 2014). However, this prior meta-analysis used outdated ES metrics, was limited to narrow AAC modes, and is now quite outdated considering the rapid increase in publication of studies on electronic forms of AAC in the past decade. Gevarter and colleagues' (2013) review uncovered unclear and inconsistent differences in the efficacy of AAC modes. Consequently, the investigators were unable to reach definitive conclusions regarding a "best approach" for persons with significant developmental disabilities. However, a number of studies yielded evidence that lower tech systems can be equally effective for some individuals as speech generating devices (SGDs).

Study Purpose

A meta-analysis was implemented to review the literature on communication functions and communicative modes taught or examined during interventions with school-age participants with ASD and/or ID who experience CCN. This review examined the effectiveness of AAC interventions when looking at moderators such as the number and type of communicative modes (e.g., verbal, gestural, AAC) targeted for intervention and communication function (i.e., behavioral regulation, joint attention, and social interaction). This review also considered the extent to which intervention effects were associated with use of aided AAC versus unaided AAC. These concepts were addressed by pursuing the following research questions:

1. To what extent do the number or type of communication modes employed during the intervention moderate treatment effects for school-aged participants with ASD and/or ID and CCN?
2. To what extent is the type of communicative function taught a moderator of treatment effects?
3. To what extent is aided versus unaided AAC a moderator of treatment effects?

Method

The current study is part of a larger systematic review and analysis of the literature on the use of AAC for individuals with ASD/ID. The literature searches were conducted between 2018 to the beginning of 2020. Details outlining the search and coding procedures are reported elsewhere Ganz et al. (2020. We used PRISMA 2020 guidelines to report our process and findings (Page et al., 2021). The PRISMA chart shown in Figure 1 illustrates the included/excluded articles during each stage of identifying potential articles for the current study. We received funding for the review from the Institute of Education Sciences (IES) and registered in the PROSPERO system (CRD42018112428).

Literature Search

Initial literature searches were conducted by a research librarian with experience conducting systematic reviews. Databases searched included *Academic Search Ultimate, ERIC, PsycINFO, Web of Science, and Proquest Dissertations & Theses Global*. Potential articles were gathered and narrowed for those focused on a dependent variable (DV) outcome analysis. The key terms included areas of AAC, social-communication, behavior outcomes, and persons who experience ASD/ID with CCN. The search identified 7,384 documents that were reviewed against the title and abstract inclusion/exclusion criteria.

Inclusion/Exclusion Criteria

The 7,384 documents identified during the literature search were screened across multiple stages throughout this meta-analysis for inclusion/exclusion. As depicted in Figure 1, the process entailed: title and abstract screening, full-text review, methodological quality screening using the WWC single-case design standards (Kratochwill et al., 2013), and DV screening by the primary investigators (PIs). We used the Rayyan web platform for title and abstract and full-text review (Ouzzani et al., 2016) and used a qualtric survey application platform for quality screening. Four coders who are doctoral students in special education reviewed for interrater reliability (IRR) at each stage of the screening process. During title and abstract screening, IRR was conducted for 100% of articles with an agreement of m = 84%. For full-text review, IRR was conducted on 69 articles (39%) with an agreement of m = 88%. IRR was conducted for 20% of the methodological quality screening using point-by-point agreement with an agreement of 90% (ranging from 82-96%). After completion of all screening stages, a total of 114 articles were included in the quantitative synthesis.

Study Outcome Characteristics Extraction

DVs for each article were separated by skills performed by the interventionist or by the person with ASD and/or ID; only DVs related to the participant with ASD/ID were included in this meta-analysis. The coders included three doctoral students in special education. We used Google forms to code this stage. The following DVs were coded.

Communicative Function(s)

A communication function was defined as the reason an individual produced the utterance being coded. Functions were based on those described by Wetherby & Prizant (1993) and included (a) joint attention, (b) social interaction, (c) behavioral regulation, or (d) communicative function not specified. A coder selected joint attention if the communicative act directed a partner's attention to an object or event external to the communicative partner. This included providing requested information that was not designed to increase turn-taking, naming objects in the environment, or providing information. A coder selected social interaction if the communicative act directed a partner's attention to oneself. This included turn-taking, telling knock-knock jokes, greetings, or requesting another's attention. A coder selected behavioral regulation for communicative acts to obtain or maintain access to an object, activity, or person; or to avoid/escape contact with an object, activity, or person. DVs coded as behavioral regulation focused on requesting a preferred item or action/activity, asking for a break, asking for help, or saying "no" to protest. IRR was conducted on 41 articles (22%) with an agreement of 89%.

Comprehension-Production

Once the documents were coded for communicative functions, the next set of codes focused on whether the DV was promoting communication production or communication comprehension. Communication production included the emission of sounds, sound combinations, spoken words, gestures, manual signs, symbols, photos or pictures, product logos, printed words, or a combination of the above to influence the communicative partner's behavior. Communication comprehension focused on deriving meaning from the communicative partner's speech, gestures, signs, symbols, or symbols. A code was entered to show whether each investigation addressed (a) comprehension, (b) production, (c) both comprehension and production or (d) not specified. IRR was conducted on 22% of the articles with an agreement of 93%.

Communication Mode

Documents were coded for communication mode through which communicative behavior was expressed. The coder could select all options that applied to the particular DV if the document stated multiple modes of communication were used. Coders selected from natural gestures, manual signs, the use of low-tech aided systems, the use of mid-to-high tech SGDs, vocalizations, and/or verbal communication. The coder selected natural gestures if the DV used head shaking, frowning, smiling, pointing, leading an individual to an object of need, or more idiosyncratic gestures such as putting their fist on one's nose to communicate "need a tissue." Manual signs were selected to describe DVs that used unaided communicative acts that relied on the targeted participant's own body and that were part of a formal sign language or system (e.g., American Sign Language). A DV that used low-tech aided systems referred to an act that did not require electrical power or batteries to operate and did not have the capability to produce speech. A common example of low-tech aided communication would be PECS or other graphic symbols housed in a wallet, board, notebook, or folder. Mid-to-high tech SGDs refers to the use of a device that relies on graphic symbols displayed in a battery-powered system that produces digitized or synthesized speech. A common example of an SGD would be Proloquo2go (AssistiveWare, 2022). A vocal communication mode referred to the production of sound(s) or sound combinations that were not intelligible word approximations. This mode excluded wheezing, snorting, and whistling, etc. that did not require the use of vocal cords. This mode included vocal sounds that the communicative partner understood due to history and experience with the participant, but may not have been understood by others. The final mode, verbal communication, was reserved for DVs that used intelligible speech or easily decipherable word approximations that could be understood by others. IRR was conducted on 22% of the articles coded for communication mode; the agreement was 87%.

Outcome Data Extraction

We collected raw outcome data from graphs provided in the included studies. The graphs were copied and pasted into Engauge Digitizer (Mitchell et al., n.d.; markummitchell.github.io/engauge-digitizer). This open-source computer program creates a graphic plane after identifying two points on the x-axis and two points on the y-axis. The program creates a corresponding x-y coordinate for each data point the user highlights. Extraction was conducted by four reviewers that were graduate-level students and had practice with the data extraction program under the training and supervision of a Co-PI. At least 20% of the graphs were reviewed by two reviewers to maintain IRR. IRR was collected for 30% of the studies during data extraction and agreement was 98%. Data were extracted from all baseline and intervention phases. Data were not extracted from generalization or maintenance phases due to the inconsistencies in these phases being presented in the studies.

Effect Size Calculations

For purposes of synthesis, we used two effect size measures that describe intervention effects for pairs of a baseline (A) and intervention (B) phase (called contrasts) for each compared variable and participant. Effect size (ES) indices included Tau (Parker et al., 2011) and log response ratio (LRR; Pustejovsky, 2018). Tau is a non-parametric pair-wise comparison derived from non-overlap or dominance statistics, which does not rely on normal distributional assumptions that may be inappropriate for single-case design data. Tau measures ES magnitude in terms of the probability that a given data point in the intervention phase is an improvement from any data point in the baseline phase. Tau-U is an extension of Tau that includes an adjustment for time trends in the baseline phase. Tau and Tau-U scores were both calculated and found to be strongly correlated. For simplicity of interpretation, Tau scores were chosen for reporting.

Tau has limitations as a measure of the strength of an intervention effect (Pustejovsky, 2019). When using Tau, intervention phases that have few overlapping data points from the baseline phases will tend to reach ceiling levels, making it impossible to discern further differences in effects. To offset the limitations of Tau, we also computed the LRR. LRR is a parametric ES measure based on the proportionate change in the average level of an outcome between phases. Limitations of LRR include that it is inappropriate to use with data sets that exhibit time trends or near-zero levels in baseline (Pustejovsky, 2018). The latter limitation is due to proportions being undefined when the denominator is equal to zero. By using both parametric and non-overlap effect size measures with complementary strengths and limitations, we can more thoroughly and robustly investigate patterns of evidence.

The SingleCaseES package (Pustejovsky & Swan, 2019) for the R programming environment was used to calculate Tau and LRR effect sizes. For Tau, the "null" standard error estimate was used. The bias-corrected estimator was used for LRR-increasing, which is appropriate for outcomes where an increase is desirable. For Tau and LRR, estimates were calculated using adjacent phases for multiple baseline designs, multiple probe designs, and treatment reversal designs. To calculate ES for alternating treatment designs, we compared data from an intervention condition to the baseline phase. When multiple AB contrasts were present in a data series, the estimates were aggregated across contrasts prior to meta-analysis (Pustejovsky & Ferron, 2017). Due to the limitations of LRR described above, estimates could only be computed for 516 outcomes (67%) from 239 participants (72%) in 93 of the included studies (82%).

Meta-Analysis and Moderator Analysis

The ES estimates calculated for this review had a hierarchical structure, where ES estimates for individual data series were nested within participants and participants were nested within studies. To appropriately account for this structure, we used multilevel meta-analysis (MLMA) models (Pustejovsky & Ferron, 2017; Van den Noortgate & Onghena, 2008) that included random effects at each level of the hierarchy (i.e., contrasts, participants, and studies). We estimated the models using restricted maximum likelihood methods with the metafor package (Viechtbauer, 2010) and calculated cluster-robust standard errors and confidence intervals for average effect sizes using the clubSandwich package (Pustejovsky, 2020). This approach yields results that are robust to the possibilities that the standard errors of individual effect size estimates could be mis-estimated or that the structure of the model's random effects could be mis-specified (Pustejovsky & Ferron, 2017).

For each research question, we estimated three MLMA models that differed in the inclusion of predictors. In the initial model, labeled Model A, we estimated average ES for each category of the focal moderator variable, without controlling for any additional study- or participant-level characteristics. In Model B, we estimated average ES for the focal moderator while controlling for differences in the other communication related moderators and in participant characteristics, including participant age, communication mode(s) prior to intervention, word use prior to intervention, and imitation use prior to intervention. Finally, Model C involved the same predictors as in Model B, along with controls for the presence or absence of specific instructional features (graphic prompts, modeling, physical prompts, preference assessment, prompt fading, reinforcement, systematic arrangement, and verbal prompts) and intervention strategies (child- versus interventionist-initiation, dispersed versus massed teaching opportunities, contrived versus embedded activity context, group versus one-on-one instructional format, limited versus varied teaching stimuli, and controlled versus natural instructional environment).

To address research question 1 (RQ1), we examined whether ES differed based on the number of communication modes used during intervention, use of specific communication modes, or use of multiple modes. These analyses were based on the full sample of effect sizes. For RQ2 and RQ3, we estimated average ES for the subsample of AAC-related outcomes only. For RQ2, we differentiated by communicative function, comparing the ES of behavioral regulation against ES of joint attention and ES of social interaction. For RQ3, we compared effects for studies that involved using unaided AAC only, aided AAC only, or the combination of aided and unaided AAC. Unaided AAC refers to the communication modes of manual sign language and natural gestures. Aided AAC refers to the communication modes of low-tech aided communication and SGDs.

Results

This review included a total of 114 studies with 330 participants. Studies were published between 1978 and 2020. Participant ages ranged from 1 year to 21 years (median age: 5 years; interquartile range: 4-9 years). The majority of participants were diagnosed with ASD (n = 228); fewer participants were diagnosed with ID (n = 85) or both ASD and ID (n = 25). Most participants used multiple communication modes prior to intervention. Data were seldom reported on participants' word use and imitation use prior to intervention. Supplementary Table S1 provides further details about participant characteristics. Regarding instructional strategies, most included studies used prompt fading, reinforcement, and systematic arrangement. Interventionist initiation, massed teaching opportunities, and one-on-one instruction were more common than child initiation, dispersed opportunities, and group instruction, respectively. Supplementary Table S2 provides further details. Most studies focused only on communication production (k = 107), rather than comprehension (k = 5), or both production and comprehension (k = 6). Supplementary Table S3 provides further information about communication outcomes in included studies.

Meta-analysis of Tau ES was conducted on 114 studies across 330 participants using 767 effects. The overall average Tau was 0.719, 95% CI [0.670, 0.768], with substantial heterogeneity at the study level ($\hat{\tau}_{study} = 0.219$) but little variation at the participant level or contrast level. The Tau results suggest that use of AAC to increase communication for participants with CCN yields moderately large effects, on average, but also that there is much variation in efficacy from study to study. LRR analysis was run on 93 studies across 239 participants using 516 effects, after excluding data series with near-zero baseline levels where LRR could not be calculated. The overall average LRR was 1.857, 95% CI [1.581, 2.133], with substantial heterogeneity at the study level ($\hat{\tau}_{study} = 1.163$), less heterogeneity at the participant level ($\hat{\tau}_{study} = 0.105$), and a very high degree of heterogeneity at the contrast level ($\hat{\tau}_{study} = 1.616$). The LRR results align with the Tau results in indicating that use of AAC yields moderately large effects, on average, and that there is substantial variation in efficacy.

Number of communication modes

To answer RQ1, we first examined the number of communication modes used during intervention. Studies were categorized as using one mode (*k* = 68 studies), two modes (*k* = 29), or three or more modes (*k* = 22, Table 1). One study did not report the communication mode for the intervention. Supplementary Figure S1 provides a graphical representation of Tau and LRR effect size estimates by number of communication modes during intervention.

Based on Model A results for the Tau ES metric, interventions with only one mode show the largest effect size with Tau = 0.754, 95% CI [0.681, 0.827]. In comparison, studies that used two modes or three or more modes had an average Tau score of 0.671 (Table 1). Although average ES estimates differed, the differences were not systematically different from zero, $F(2,22.9) = 1.1$, $p = .345$. These patterns were consistent across all three models. When analyzing the data using LRR effect size metric (Table 2), studies that employed three or more modes had the largest effect size, LRR = 1.887, 95% CI [1.091, 2.682], followed by studies that used one communicative mode and studies that utilized two modes. Average LRR effect sizes across modes were not statistically distinct, $F(2, 12.4) = 0.0$, $p = .992$ (Table 2).

Type of Communication Mode

Included studies examined communication modes of low-tech aided AAC (*k* = 18), mid- or high-tech aided AAC (*k* = 26), manual sign/natural gestures (*k* = 18), verbalization/vocalization (*k* = 11), or multiple modes (*k* = 50; Table 1). One study did not report the type of communication mode used in the intervention. Table 1 reports average

Tau effect sizes by communication mode during intervention, based on each of three meta-regression models. Supplementary Figure S2 provides a graphical representation of Tau and LRR estimates by type of communication modes during intervention, along with the average ES estimates from Models A, B, and C. Across all three models, larger effects were exhibited in studies that used low-tech or mid-to-high tech aided AAC, followed by studies that used verbalization/vocalization and studies that used multiple modes during intervention. Studies that used manual signs or natural gestures had the lowest effects. However, differences between categories were not statistically distinct in any of the models examined, and a high degree of between-study heterogeneity remained even in Models B and C, which included additional control variables.

Table 2 reports the average LRR effect sizes for the type of communication modes used during the interventions. Descriptively, studies that used low-tech or mid-to-high tech aided AAC or used multiple modes tended to have somewhat larger LRR effects, while studies that focused on manual signs and/or natural gestures and studies that focused on verbalizations and/or vocalizations as the intervention communication mode had smaller effect sizes. Differences between communication modes were statistically significant based on Model A, $F(4, 12.3) = 3.3$, $p = .049$. However, differences were not statistically distinguishable when controlling for additional participant or intervention characteristics in Models B or C.

Communication Functions

Across the identified studies, AAC communication functions examined included behavioral regulation (k = 61), joint attention (k = 21), social interaction (k = 18), or multiple functions (k = 12; Supplementary Table S3). For purposes of analysis, we estimated meta-regression models only for the subset of data series involving AAC-related outcomes. Supplementary Figure S3 provides a graphical representation of effect size estimates and model results by function of communication. When based on the Tau ES metric, there were no statistically distinct differences in average effects by communication function (Table 3). Descriptively, studies that taught multiple functions of communication and those that taught social interaction tended to have larger average effect estimates than those that focused on joint attention or behavior regulation.

Using the LRR metric, there were again no statistically distinct differences in average effects by communication function (Table 4). Descriptively, studies that taught multiple functions had the largest average ES estimates in all three models (e.g., LRR = 2.383 in Model A), similar to the pattern of results based on Tau. However, unlike results based on Tau, studies that taught behavioral regulation tended to have the next-largest effect size estimates (e.g., LRR = 2.207 in Model A), while studies that taught joint attention or social interaction had smaller average effects. This pattern was consistent across all three models.

Aided versus unaided AAC

Most included studies looked at exclusively aided AAC (k = 62); fewer looked at exclusively unaided AAC (k = 26), both aided and unaided AAC (k = 20), or verbalization/vocalization alone (k = 14; Supplementary Table S3). Supplementary Figure S4 provides a graphical representation of ES estimates and model results for comparisons of aided AAC versus unaided AAC. Using the Tau metric and the subset of data series with AAC-related outcomes, the largest ES estimates were observed in studies that used exclusively aided AAC, followed by studies that used both aided and unaided AAC (Table 3). Studies that utilized exclusively unaided AAC had the smallest Tau estimates across all three models. Although there seem to be differences across these categories, these differences were not statistically distinguishable in any of the three models. Similarly, differences in average LRR effects were not statistically distinguishable in any of the models (Table 4). Descriptively, studies that used exclusively aided AAC had larger average LRR estimates than studies that used other combinations of AAC models.

Discussion

This systematic review and meta-analysis reviewed a large body of evidence from single-case research on AAC interventions for individuals with ASD and ID and considered potential differences related to outcomes that were targeted for intervention. For most participants, communication modes implemented during intervention included two or more modes (41%), followed by mid-to-high-tech aided AAC only (21%), low-tech aided AAC only (16%), manual sign language or gesture only (14%), or verbalization or vocalization only (7%). The most common combinations of multiple modes were low-tech with mid-to-high-tech aided AAC (k = 9 studies, 31 participants); manual sign/natural gesture with verbalization/vocalization (k = 8 studies, 22 participants); manual sign/natural gestures with verbalization/vocalization and mid-to-high-tech aided AAC (k = 7 studies, 21 participants); and mid-to-high-tech aided AAC with verbalization/vocalization (k = 6 studies, 20 participants); Supplementary Table S4 provides further details. The distribution of aided versus unaided AAC indicates that more participants used exclusively aided AAC (53%), followed by exclusively unaided AAC (20%), both aided and unaided AAC (17%), and exclusively verbalizations or vocalizations (10%). There were substantially more interventions that did not involve verbal or vocal output (66%) than those that involved vocal or verbal output (33%). This pattern indicates a disconnect between research practice and contemporary guidelines, the latter of which recommend a multimodal approach to AAC (Johnston et al., 2012). Most participants' interventions consisted of a single communication mode (56%), followed by 2 modes (25%), or 3 or more modes (18%).

Almost all of the identified studies focused on communication production rather than comprehension. This is not surprising; however, it is problematic. However, there is good reason to believe that production and comprehension interact during the language development process. For example, results of a critically appraised topic reported by Elmquist and colleagues (2019) discuss evidence that aided-AAC interventions teaching symbol production can increase speech comprehension and graphic symbol comprehension (even though comprehension may not be an intervention target) associated with productive use of AAC strategies. Several studies (Brady et. al., 2015; Dada & Alant, 2009; Drager et al., 2006; Harris & Reichle, 2004) addressed the relationship between comprehension and production in AAC. In each of the preceding studies, participants made comprehension gains even though production was the intervention objective. Some participants responded better than others to treatment, suggesting that there may be learner characteristics that moderate or mediate intervention outcomes. Potential moderators may include the participant's ability to "fast map" (Drager et al., 2006; Harris & Reichle, 2004), and the participant's speech comprehension abilities (Dada & Alant, 2009). Consequently, it is important to at least describe comprehension skills prior to intervention (Brady, 2001). However, we found that pre-intervention comprehension skills were rarely described in AAC intervention studies.

With respect to communicative functions, the majority of the participants' interventions involved communication functions of behavioral regulation (51%) rather than joint attention (19%), social interaction (16%), or multiple communication functions (10%). This aligns with prior findings (Ganz et al., 2017; Holyfield et al., 2017; Iacono et al., 2016; Morin et al., 2018), but is somewhat problematic. As mentioned earlier, behavior regulation acts are reinforced by the delivery of things or activities that the learner values, in the case of requests, and removal of aversive things or activities, in the case of protests. Both social interaction and joint attention are reinforced via social reinforcement. For many learners with ASD, social contact with others can be more challenging. Thus we suspect that many intervention researchers choose to teach behavior regulation acts which are, in some respects, easier targets.

There were few statistically discernible differences for either effect size metric for any of the focal moderators examined, even when controlling for participant characteristics and intervention features. However, there were some interesting trends in ES magnitudes. Regarding communication modes implemented during intervention, Tau effects for low- and mid-to-high-tech aided AAC are around .8, while others are .7 or lower. These results are not significant because of the heterogeneity which obscure our ability to find systematic differences. For communication mode, the pattern of differences in ES magnitude is similar for LRR.

Similar patterns were apparent for communicative functions. There were no statistically significant differences in ES across communicative functions, although Tau was largest for studies that taught participants multiple functions, then social interaction, then joint attention, then behavioral regulation. It may be that those for whom social and joint attention DVs were selected were more sophisticated communicators at the onset of intervention. However, this was not discernable given the limited participant descriptions available in most studies. When controlling for the participant characteristics for which we do have measures, some of the differences between the ES were diminished. These average effects were sensitive to whether or not we control for those characteristics, indicating that communication functions are associated with other participant characteristics that are not well reported in the current literature. Similar outcomes were found for LRR, that is, no statistically significant differences in ES were apparent; although studies addressing multiple functions had higher effects, followed by behavioral regulation, while joint attention and social interaction had smaller effects. These discrepancies may have arisen because Tau measures degree of overlap between baseline performance data points and intervention, whereas LRR measures proportional change in average performance from baseline to intervention phases, or because the analysis of LRR effects included fewer studies than the analysis of Tau effects, or due to random chance (given that differences between communication functions were not statistically distinct for either ES metric).

When considering only AAC-related outcomes, although not statistically discernible, exclusive use of aided AAC yielded higher effects than use of both aided and unaided AAC, both of which were higher than effects for unaided AAC. This finding is commensurate with prior literature suggesting that some individuals who use AAC, particularly those with ASD, perform better with aided AAC, which requires fewer cognitive demands than unaided AAC. That is, unaided communication requires the learner to retrieve signed words or gestures from memory (Johnston et al., 2012). That said, the heterogeneity of the outcomes suggests a high degree of individualization when selecting an AAC mode for a minimally- or nonverbal person with ASD/ID. These effects are roughly the same when controlling for participant characteristics and intervention features.

There was a substantial amount of heterogeneity in the distribution of ES across studies. Some of the heterogeneity may be due to differences in implementation of instructional variables that were infrequently described or measured in the literature to date, and may relate to the educators' choices based on the characteristics of their participants. That said, controlling for differences based on the measures of participant characteristics and intervention characteristics that we were able to extract from the primary studies did not explain a substantial amount of the variation in ES. While standardized tools that may be used to provide comparable assessment and reporting of participant characteristics do exist (e.g., *Autism Diagnostic Observation Scale* [Lord et al., 2012]), the studies included in this review did not consistently apply them, which limited our ability to control for or determine effects based on differences on diagnostic and educational assessments. Moreover, most standardized and normed assessments do not include standards for modification for individuals who use AAC – a related area where research is needed. Further, the studies have depended heavily on researcher-developed, rather than manualized AAC implementation protocols, which might have led to a substantial amount of heterogeneity in implementation. Variation across intervention protocols impeded substantive comparisons to be made.

Results in Relation to Prior Reviews and Meta-analyses

Our findings were similar to those of prior reviews and meta-analyses. For instance, prior work found substantial heterogeneity in characteristics of participants and in instruction in a range of communicative functions (Chazen et al., 2021; Ganz et al., 2017; Iacono et al., 2016; Logan et al., 2017). Similar to other reviews, we found that instruction focused on behavior regulation more often than more socially advanced communicative functions (Holyfield et al., 2017; Morin et al., 2018), although those reviews were limited to less expansive populations or AAC modes. Similar to other meta-analyses (Ganz et al., 2017), we did not find significant differences between communicative functions.

Limitations and Future Research

This large comprehensive systematic review and meta-analysis has several limitations. In particular, there was insufficient data to test some potential moderators. For example, few studies investigated outcomes related to communication comprehension. While an emphasis on production of AAC-based communication is logical, studies investigating the impact of AAC implementation on communication comprehension would reflect the process of development of typical communication, which generally involves comprehension preceding production (Brady, 2001). Further, lack of sufficient descriptive information on participant characteristics, particularly standardized diagnostic and social-communication skill assessments, meant that we were unable to determine what participant characteristics were associated with better performance with particular communication modes, for example. This prevents customization of AAC interventions, choice of modes, use of multiple communication modes, and determination of communicative functions to teach based on the needs and strengths of the participants.

Although we believe that we selected the ES measures that were best suited for these data, there were nonetheless some limitations arising from the use of non-overlap ES metrics. Tau limitations include loss of sensitivity when there is near zero overlap between phases. That is, a large Tau effect may be obtained although two graphs may have very different average mean differences between phases when there is little overlap. This ceiling effect created a large grouping of Tau estimates at or near 1.0, which may have contributed to the lack of statistically significant differences we found between moderator categories. LRR also has some limitations, including that it is not appropriate for data sets with baseline data that include near zero levels. As a result, a non-trivial number of studies that were included in the Tau analyses were excluded from the LRR analyses.

Future research is needed to fill a number of gaps in this literature that remain underreported. As noted above, participant characteristics are not well described; single-case researchers could better provide standardized diagnostic, cognitive, and social-communication assessment information; information on the mastery of joint attention and imitation skills; and prior use of communication modes. Such information would allow for better customization of interventions for this population.

Conclusion

In summary, results of this meta-analysis suggest that there is a need for a more rigorous description of participants at the outset of intervention. Having more detailed participant descriptions offers several benefits. First, it could help to identify critical skills that mediate intervention success. Second, the continued prevalence of selecting behavior regulation as an intervention target suggests a need for research strategies to identify or establish social contact with others as a more viable reinforcer for many learners. Third, even though current practices call for a multimodal approach, evidence from this review suggests that is frequently not the case. In fact, it is possible that many researchers are unaware of the learner's communicative modes prior to the implementation of the independent variable.

Often the measuring stick for the success of an intervention is teaching opportunities to criterion or number of sessions required to reach mastery. Clearly these are important metrics. However, little comprehensive attention has been given to long term maintenance and generalization of newly established behavior. We have learned from the functional communication training literature (see Reichle & Wacker, 2017) that there are many behaviors in a learner's repertoire that potentially compete with newly established behavior and that it is easy for resurgence of one or more of these behaviors to occur. Consequently, it is important that comprehensive intervention protocols go beyond isolated settings, persons, and teaching examples. Although the field is improving in implementing at least some intervention opportunities in authentic environments, we have rarely examined systematically the effects of environmental features, particularly naturalistic instructional features, on the use of newly established communicative behaviors.

We are encouraged by the success of AAC and note that it is becoming increasingly accepted by practitioners and a range of natural communicative partners. We look forward to increased systematization in the ways that research is reported to facilitate an aggregation of research outcomes that can result in a stronger evidence base in the years ahead, which would allow for more customization of instruction based on participant need and characteristics.

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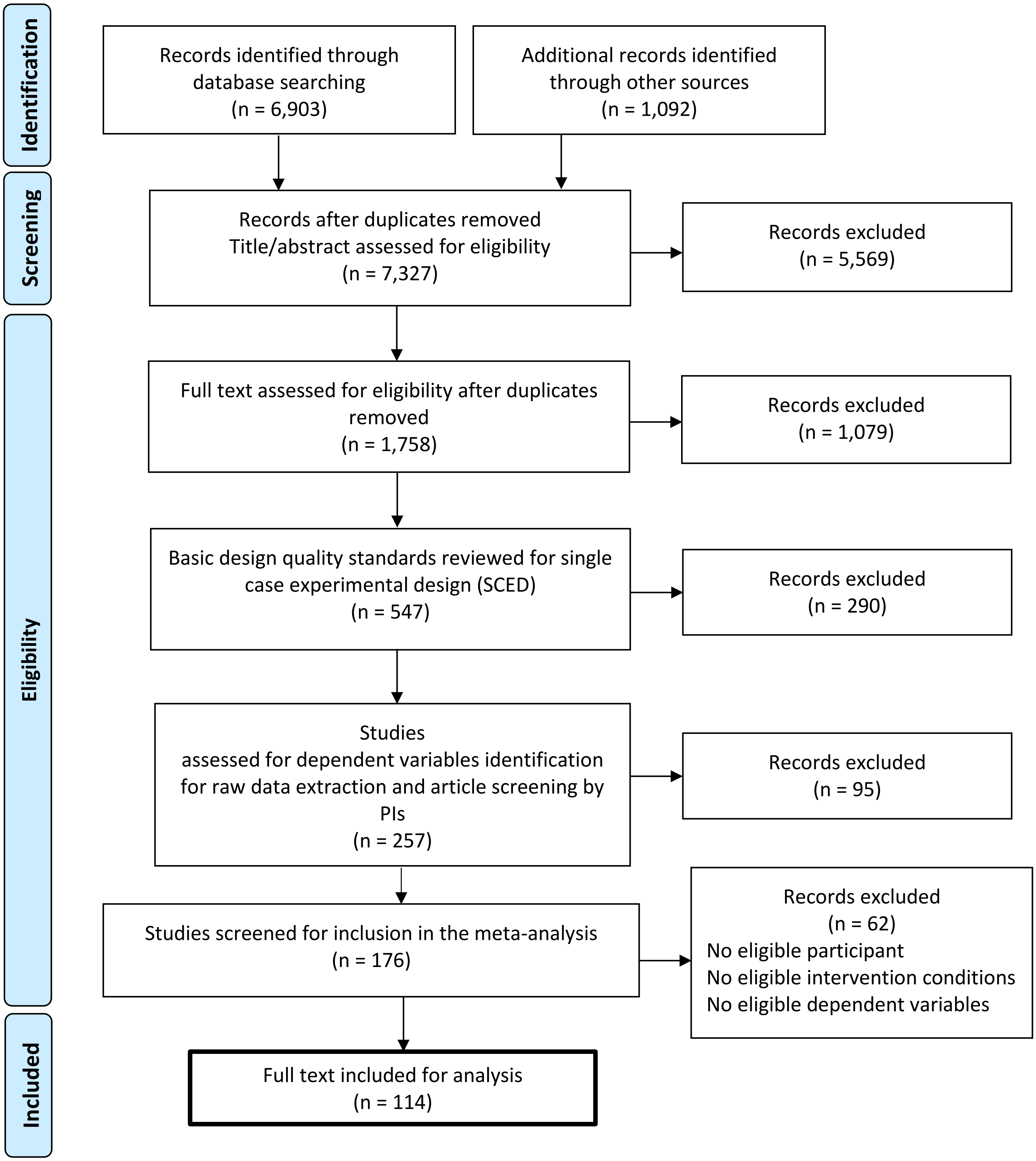
Figure 1

PRISMA Flowchart



Note: Flowchart based on Moher, D., Liberati, A., Telzlaff, J., Altman, D. G. (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Medicine, 6*(7): e1000097. doi: 10.1371/journal.pmed1000097.

***Table 1**. Average effect sizes based on Tau(AB) metric*

				Model A		Model B		Model C	
Category	**k**	**P**	**N**	**Est.**	**95% CI**	**Est.**	**95% CI**	**Est.**	**95% CI**
Number of communication modes				F(2,22.9) = 1.1	p = .345	F(2,20.3) = 0.9	p = .403	F(2,18.3) = 0.3	p = .745
1 mode	68	193	452	0.754 (0.037)	[0.681, 0.827]	0.759 (0.036)	[0.688, 0.831]	0.748 (0.036)	[0.675, 0.822]
2 modes	29	86	196	0.671 (0.071)	[0.524, 0.817]	0.711 (0.070)	[0.567, 0.855]	0.702 (0.069)	[0.559, 0.844]
3+ modes	22	64	113	0.671 (0.048)	[0.566, 0.775]	0.670 (0.059)	[0.541, 0.798]	0.695 (0.069)	[0.545, 0.846]
Not reported	1	3	6	0.629 (0.078)	[-0.361, 1.618]	0.539 (0.135)	[0.045, 1.033]	0.784 (0.223)	[0.253, 1.314]
Communication modes during				F(4,26.5) = 1.7	p = .170	F(4,23.2) = 1.9	p = .144	F(4,20.5) = 1.7	p = .191
Low-tech aided AAC	18	57	157	0.831 (0.105)	[0.608, 1.054]	0.820 (0.118)	[0.570, 1.070]	0.780 (0.124)	[0.518, 1.042]
Mid-to-high-tech aided AAC	26	75	118	0.797 (0.050)	[0.693, 0.901]	0.820 (0.048)	[0.718, 0.921]	0.823 (0.051)	[0.714, 0.932]
Manual sign/natural gestures	19	50	126	0.655 (0.079)	[0.488, 0.822]	0.652 (0.088)	[0.468, 0.836]	0.635 (0.094)	[0.436, 0.833]
Verbalization/vocalization	14	36	64	0.746 (0.115)	[0.494, 0.998]	0.755 (0.125)	[0.483, 1.027]	0.773 (0.144)	[0.458, 1.089]
2 or more categories	47	139	296	0.659 (0.041)	[0.577, 0.741]	0.683 (0.040)	[0.602, 0.763]	0.688 (0.040)	[0.607, 0.769]
Not reported	1	3	6	0.628 (0.080)	[-0.388, 1.645]	0.546 (0.131)	[0.097, 0.994]	0.752 (0.243)	[0.186, 1.319]

k = Number of studies. P = Number of participants. N = Number of data series. Est. = Average effect size estimate. SE = Standard error. CI = confidence interval. F = F-statistic for test that average effect sizes are equal across categories; numerator and denominator degrees of freedom are reported in parentheses after the test statistic.

Model A includes only the focal moderator variable. Model B includes the focal moderator variable and controls for type of communication modes during intervention, communication functions, and participant characteristics. Model C includes the focal moderator variable and the controls from Model B, as well as controls for instructional features and intervention characteristics.

Table 2*. Average effect sizes based on log response ratio metric*

				Model A		Model B		Model C	
Category	**k**	**P**	**N**	**Est.**	**95% CI**	**Est.**	**95% CI**	**Est.**	**95% CI**
Number of communication modes				F(2,12.4) = 0.0	p = .992	F(2,8.8) = 0.0	p = .994	F(2,8.0) = 0.0	p = .963
1 mode	51	132	291	1.844 (0.191)	[1.457, 2.230]	1.880 (0.205)	[1.465, 2.295]	1.870 (0.223)	[1.417, 2.323]
2 modes	24	59	118	1.817 (0.344)	[1.102, 2.532]	1.838 (0.402)	[1.003, 2.673]	1.744 (0.428)	[0.854, 2.635]
3+ modes	22	58	101	1.887 (0.361)	[1.091, 2.682]	1.839 (0.444)	[0.836, 2.841]	1.940 (0.485)	[0.818, 3.062]
Not reported	1	3	6	2.813 (1.198)	[-12.409, 18.036]	4.715 (1.922)	[-1.318, 10.749]	6.046 (1.826)	[1.833, 10.259]
Communication modes during				F(4,14.2) = 1.8	p = .193	F(4,12.1) = 2.0	p = .161	F(4,9.7) = 1.1	p = .403
Low-tech aided AAC	15	44	120	2.016 (0.575)	[0.778, 3.253]	1.903 (0.629)	[0.555, 3.252]	1.822 (0.618)	[0.505, 3.138]
Mid-to-high-tech aided AAC	19	48	75	2.409 (0.277)	[1.796, 3.022]	2.502 (0.270)	[1.908, 3.096]	2.477 (0.319)	[1.757, 3.196]
Manual sign/natural gestures	12	29	57	1.460 (0.290)	[0.816, 2.103]	1.445 (0.291)	[0.801, 2.089]	1.376 (0.323)	[0.656, 2.095]
Verbalization/vocalization	13	32	51	0.722 (0.438)	[-0.236, 1.680]	0.797 (0.464)	[-0.209, 1.803]	0.938 (0.593)	[-0.368, 2.243]
2 or more categories	42	107	207	1.966 (0.210)	[1.541, 2.391]	2.003 (0.233)	[1.531, 2.475]	2.001 (0.242)	[1.509, 2.492]
Not reported	1	3	6	2.823 (1.359)	[-14.439, 20.086]	4.218 (1.684)	[-0.864, 9.300]	5.244 (1.858)	[1.027, 9.460]

k = Number of studies. P = Number of participants. N = Number of data series. Est. = Average effect size estimate. SE = Standard error. CI = confidence interval. F = F-statistic for test that average effect sizes are equal across categories; numerator and denominator degrees of freedom are reported in parentheses after the test statistic.

Model A includes only the focal moderator variable. Model B includes the focal moderator variable and controls for type of communication modes during intervention, communication functions, and participant characteristics. Model C includes the focal moderator variable and the controls from Model B, as well as controls for instructional features and intervention characteristics.

***Table 3**. Average effect sizes for AAC-related outcomes based on Tau(AB) metric*

				Model A		Model B		Model C	
Category	**k**	**P**	**N**	**Est.**	**95% CI**	**Est.**	**95% CI**	**Est.**	**95% CI**
Communication functions				F(3,12.8) = 1.3	p = .305	F(3,15.5) = 2.0	p = .158	F(3,16.4) = 1.9	p = .163
Behavioral regulation	49	135	287	0.722 (0.038)	[0.645, 0.798]	0.720 (0.039)	[0.641, 0.799]	0.719 (0.047)	[0.623, 0.814]
Joint attention	13	39	87	0.737 (0.089)	[0.542, 0.932]	0.780 (0.100)	[0.566, 0.994]	0.702 (0.128)	[0.432, 0.972]
Social interaction	7	23	48	0.801 (0.089)	[0.578, 1.023]	0.941 (0.093)	[0.724, 1.157]	0.884 (0.114)	[0.630, 1.139]
Multiple	6	21	59	0.885 (0.068)	[0.702, 1.068]	0.831 (0.065)	[0.670, 0.993]	0.895 (0.079)	[0.710, 1.080]
Not reported	2	6	6	0.868 (0.110)	[-0.524, 2.259]	1.025 (0.110)	[0.397, 1.654]	0.824 (0.250)	[0.150, 1.497]
Aided AAC vs. unaided AAC				F(2,16.0) = 1.4	p = .275	F(2,15.5) = 1.2	p = .332	F(2,15.0) = 0.8	p = .473
Both aided and unaided AAC	8	30	62	0.717 (0.066)	[0.558, 0.876]	0.776 (0.091)	[0.564, 0.987]	0.758 (0.127)	[0.475, 1.041]
Exclusively aided AAC	51	148	309	0.801 (0.042)	[0.716, 0.886]	0.830 (0.054)	[0.719, 0.941]	0.835 (0.063)	[0.705, 0.964]
Exclusively unaided AAC	18	46	113	0.619 (0.092)	[0.424, 0.814]	0.630 (0.105)	[0.411, 0.850]	0.634 (0.118)	[0.386, 0.883]
Not reported	1	3	3	0.756 (0.021)	[0.491, 1.021]	0.519 (0.135)	[-0.095, 1.133]	0.676 (0.507)	[-0.452, 1.804]

k = Number of studies. P = Number of participants. N = Number of data series. Est. = Average effect size estimate. SE = Standard error. CI = confidence interval. F = F-statistic for test that average effect sizes are equal across categories; numerator and denominator degrees of freedom are reported in parentheses after the test statistic.

Model A includes only the focal moderator variable. Model B includes the focal moderator variable and controls for combination of AAC modes during intervention, use of vocalization/verbalization during intervention, communication functions, and participant characteristics. Model C includes the focal moderator variable and the controls from Model B, as well as controls for instructional features and intervention characteristics.

***Table 4**. Average effect sizes for AAC-related outcomes based on log response ratio metric*

				Model A		Model B		Model C	
Category	**k**	**P**	**N**	**Est.**	**95% CI**	**Est.**	**95% CI**	**Est.**	**95% CI**
Communication functions				F(3,10.0) = 2.6	p = .111	F(3,11.9) = 1.3	p = .330	F(3,10.8) = 2.5	p = .113
Behavioral regulation	38	85	140	2.207 (0.265)	[1.670, 2.745]	2.202 (0.294)	[1.599, 2.804]	2.453 (0.364)	[1.686, 3.219]
Joint attention	6	18	42	1.355 (0.351)	[0.447, 2.263]	1.605 (0.575)	[0.193, 3.018]	1.875 (1.095)	[-0.832, 4.582]
Social interaction	7	20	44	1.343 (0.191)	[0.872, 1.813]	1.304 (0.345)	[0.505, 2.104]	0.087 (0.673)	[-1.460, 1.634]
Multiple	5	18	56	2.383 (0.577)	[0.775, 3.991]	2.502 (0.676)	[0.745, 4.260]	2.509 (0.831)	[0.517, 4.501]
Not reported	2	5	5	1.881 (0.011)	[1.743, 2.020]	1.780 (0.493)	[0.167, 3.393]	1.145 (1.013)	[-1.158, 3.449]
Aided AAC vs. unaided AAC				F(2,12.0) = 0.7	p = .527	F(2,11.7) = 1.3	p = .317	F(2,15.6) = 1.4	p = .273
Both aided and unaided AAC	6	19	30	1.791 (0.483)	[0.542, 3.041]	1.495 (0.623)	[-0.011, 3.001]	2.290 (1.058)	[-0.037, 4.618]
Exclusively aided AAC	40	98	206	2.151 (0.249)	[1.647, 2.654]	2.527 (0.275)	[1.944, 3.109]	2.412 (0.311)	[1.754, 3.069]
Exclusively unaided AAC	11	26	48	1.666 (0.338)	[0.912, 2.419]	1.913 (0.407)	[1.037, 2.790]	1.422 (0.477)	[0.415, 2.429]
Not reported	1	3	3	1.864 (0.331)	[-2.336, 6.064]	2.722 (0.613)	[1.109, 4.335]	2.794 (2.299)	[-2.406, 7.993]

k = Number of studies. P = Number of participants. N = Number of data series. Est. = Average effect size estimate. SE = Standard error. CI = confidence interval. F = F-statistic for test that average effect sizes are equal across categories; numerator and denominator degrees of freedom are reported in parentheses after the test statistic.

Model A includes only the focal moderator variable. Model B includes the focal moderator variable and controls for combination of AAC modes during intervention, use of vocalization/verbalization during intervention, communication functions, and participant characteristics. Model C includes the focal moderator variable and the controls from Model B, as well as controls for instructional features and intervention characteristics.