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REVIEW ARTICLE

A Systematic Review of Research Comparing Mobile Technology Speech-Generating Devices to Other AAC Modes with Individuals with Autism Spectrum Disorder

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Abstract

As 30% of individuals with autism spectrum disorder (ASD) demonstrate difficulties with vocal output, augmentative and alternative communication (AAC) intervention can provide a means for those persons to have the ability to communicate with others. To determine the most effective mode of AAC for individuals with ASD, practitioners must have access to current comparative research in order to make evidence-based decisions. This systematic review searched ERIC, Google Scholar, PsycINFO, and Science Direct databases for studies that compared AAC modes, including mobile technology based speech-generating devices, in intervention with individuals with ASD. The search yielded nine (n = 9) alternating treatment design single case studies including a total of 36 participants with ASD with a mean age of seven (range: 3–13). The included studies were compared to evaluate operants, evidence-based best practices, preferences, and participant performance across AAC modes. Visual and statistical analyses indicated most participants not only preferred using the SGD but had performed better when using such devices compared to picture exchange and manual sign. Findings suggest that practitioners should consider using mobile technology based SGDs to promote verbal behavior from children with a diagnosis of ASD. Additionally, research evaluating verbal operants beyond the initial mand (request) and incorporating participants who are adolescents or adults is needed.

Keywords Augmentative and alternative communication (AAC) · Speech generating device (SGD) · Autism spectrum disorder (ASD) · Picture exchange (PE) · Manual sign (MS)

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Introduction

Autism spectrum disorder (ASD) is a neurological disorder with behavioral manifestations which impacts two behavioral domains: social communication and repetitive and restricted patterns of behaviors and interests (American Psychiatric Association, 2013). The social communication impairments can vary from mild to severe and it is estimated that 30% of individuals with ASD do not develop functional vocal output (Wondka et al., 2013). For those individuals, augmentative and alternative communication (AAC) technologies and strategies can be used to either replace or supplement vocal abilities, allowing them to have a means by which to communicate with individuals (Ganz, 2015; Light et al., 2019; Mirenda, 2003).

The use of AAC technologies in educational and clinical settings for individuals with ASD is common, as is the use of systematic communication instruction using Skinner's (1957) approach to verbal behavior (Tincani et al., 2020). Researchers and clinicians have successfully used Skinner's approach to verbal behavior to teach communication skills to individuals who use AAC, including those with ASD (for example, see Lorah, 2016). As such, the use of Skinner's approach to verbal behavior, including an analysis of the functional units of verbal operants is commonly used within the literature base and was thus, included in this review (see Table 1).

AAC technologies and strategies include a range of communication modes. For instance, some AAC modes require nothing do not require any external equipment, such as manual sign (e.g., American Sign Language, ASL) (Gevarter et al., 2013). Such modes are considered no-tech or unaided AAC options. Other options, however, require external equipment, ranging from low- to high-tech such as those using printed picture symbols (e.g., Picture Exchange Communication System®, PECS®; Bondy & Frost, 1994) to those using computer technology with voice output (i.e., speech-generating devices [SGD] or voice output communication aids [VOCA]) (Gevarter et al., 2013).

When selecting an AAC mode for an individual with ASD, practitioners should consider the user's baseline ability (i.e., imitation repertoire, etc.) and mode preference, as well as the cost and durability of using a specific device (Lorah et al., 2018). Historically, SGD and VOCA were cost prohibitive to many learners with ASD given insurance and/or educational policies that assist with the funding of such devices (Lorah et al., 2015). However, given recent advancements in the development of affordable, powerful, and portable handheld mobile technology devices (which can be outfitted with software to function as SGD and VOCA), there are more options available when selecting an AAC mode (Lorah et al., 2015).

There are several comparative evaluations on the effectiveness and user preference of various AAC modes; the majority of these studies use single case design (i.e., van der Meer et al., 2012; Lorah et al., 2013; van der Meer et al., 2013; Lorah, 2016). Conducing one study using single case design answers a narrow range of questions; therefore, the value of such research is demonstrated only when placed

Table 1 Verbal operants (Skinner, 1957)

Operant	Definition	Example
Mand	Under the control of a motivating operation; response specifics reinforcer	Child says apple, child receives an apple
Echoic	Response has point-to-point correspondence with antecedent stimulus; generalized conditioned reinforcement	Teacher says "apple", child says "apple"
Intraverbal	Response does not have point-to-point correspondence with verbal stimulus; generalized conditioned reinforcer	Teacher says "What do you want?", child says "apple"
Tact	Response is evoked by non-verbal stimulus; generalized conditioned reinforcement	Child sees an apple and says "apple", teacher says "you're right! That is an apple!"
Textual	Response is evoked by written stimulus and has point-to-point correspondence; generalized conditioned reinforcement	Child sees written word "apple" and says "apple"
Transcription	Response includes writing and spelling words that are occasioned by a verbal stimulus and has point-to-point correspondence; generalized conditioned reinforcement	Teacher says word "apple", student writes word "apple"

This table shows the operationally defined verbal operants which were identified in the nine included studies

in the context of the larger literature base (Ledford & Gast, 2018). Synthesizing studies across outcomes through a systematic literature review, including a meta-analysis of effects, is one way to place single case evaluations into that larger context (Ledford & Gast, 2018). There are three central reasons for the inclusion of systematic reviews in the literature base outlined by Pustejovsky and Ferron (2017). First, they are important tools in establishing evidence-based best practices. Second, they can be helpful in determining if and to what degree variation in treatments exist. Finally, they can contribute to the development of single case design broadly (Pustejovsky & Ferron, 2017). As such, the continued synthesis of comparative studies relating to AAC modes for individuals with ASD is valuable to not only practitioners and teachers, but also the field of single case design in general. One characteristic that makes this review unique is the combination of both visual and statistical analysis of effects. Thus, the purpose of this paper is to offer a synthesis and meta-analysis of comparative AAC studies that use mobile technology as a speech-generating device.

Further, a major consideration in terms of comparison studies is the instructional methodologies used. For example, while PECS (Bondy & Frost, 1994) is considered an evidence-based best practice (Steinbrenner et al., 2020), other picture-based modes that do not follow the PECS instructional protocol may or may not use an evidence-based instructional procedure. In other words, it is not the mode that is evidence-based, but rather the teaching procedures used in combination with the AAC technology or strategy (i.e., mode; Lorah et al., 2015). Thus, this review includes an analysis of not only the mode, but also the instructional approaches used within the procedures of the studies reviewed, using the National Clearinghouse on Autism Evidence and Practice (Steinbrenner et al., 2020) as an indicator of evidence-based practices.

Research Objectives

In summary, the purpose of this study was to synthesize and summarize the comparative evaluations of AAC modes that include hand-held computing devices (e.g., the iPad®) as a SGD. The purpose of such a synthesis and summary is to provide clearer clinical guidelines about decision-making in AAC assessment and intervention by compiling the research that evaluates the comparative effects of different AAC modes, including an evaluation of instructional procedures. Included in this review is an analysis of the instructional methods used for the comparison of those modes. Visual and statistical analyses were used to determine which mode produces the fastest and most robust acquisition of a communication repertoire across participants and which mode is most preferred by participants (for those studies that included an evaluation of participant device preference). Finally, each of the studies will be evaluated for quality indicators and given an appraisal.

Method

This study used a systematic review methodology to rigorously identify, compile, and analyze single-subject AAC intervention comparative research data for individuals with ASD. Procedures for article searches, article coding, and process and result reporting followed the Cochrane Handbook for Systematic Reviews of Interventions (Higgins et al., 2019). All procedures for identifying, including, and evaluating research articles (outlined below) were developed and documented prior to beginning the systematic review process.

Inclusion Criteria

To be included in this systematic review, a study must have directly compared two or more AAC modes using an alternating treatments design or a variation thereof (Ledford & Gast, 2018) in intervention with individuals with ASD. Additionally, the intervention must have focused directly on intervention with the participants using AAC, including mobile technology (e.g., an iPad) outfitted to function as a SGD. For instance, articles that measured parent or teacher training related to AAC use were excluded as not being directly relevant to the focus on this investigation. Finally, the methods of the reviewed studies must have been described in sufficient detail for the authors to make a determination as to the quality indicators (see Table 2) and must have included a graph for visual inspection.

Search Procedures

A systematic search was conducted in order to identify peer-reviewed studies that compared the use of various modes of AAC. The article extraction occurred during the months of January through March 2019. The ERIC, Google Scholar, PsycINFO, and Science Direct databases were searched online, using combinations of the following search terms with Boolean operators and truncation: *speech generating device, augmentative and alternative communication, manual sign, picture exchange, picture exchange communication system,* and *autism spectrum disorder*. All search results were screened when feasible, but for combinations that returned several hundreds or thousands of results, screening continued until at least 100 articles were screened with no new relevant results. This decision was made because the results after the first few dozen were rarely relevant. Two additional articles were located through reverse citations of articles.

A total of 48 articles were identified using these criteria. The abstracts of these articles were then screened using the determined inclusion criteria. Studies were excluded if it was clear by their abstracts that they did not meet the established criteria. The remaining 19 studies were divided into two batches, which were each read and screened by three of the authors. For each study, the three authors separately made a determination about whether it met inclusion criteria, and then compared results. Ten studies were eliminated at this point because they did not meet the

Table 2 Extracted data from included studies

References	Operants	Name, age	Devices	Exp. design	Results acquired (%)	Results maintenance (%)	Results preference (%)	EBP	Quality indicators	Appraisal
Agius and Vance (2016)	Mand, Tact	Elias (3) Larry (4) Fred (4)	PE, SGD	ATD within a MBD	Elias: (SGD: 73, range: 0–100; PE: 90, range: 60–100) Larry: (SGD: 78, range: 20–100; PE: 85, range: 80–100) Fred: SGD- 82, range: 50–100; PE: 92, range: 80–100)	Elias: (SGD: 40; PE: 90, range: 60–100) Larry: (SGD: 100; PE: 97, range: 90–100) Fred: (SGD: 20; PE: 93 range: 80–100)	Elias: (SGD: 36, PE: 64) Larry: (SGD: 100, PE: 0) Fred: (SGD: 19, PE: 81)	DTT, prompting, reinforcement, task analysis, time delay	No experimental control	Conclusive
Couper et al. (2014)	Mand, Tact, Intraverbal	Henry (5.3) Cameron (4.2) Andy (7.1) Simon (12.3) Nico: (8.11) Andrew: (6.6) Jimmy: (5.1) Shane: (5.2) Edward: (7.11)	PE, MS, SGD	ATD within a MBD	Henry: (SGD: 68, range: 20–100; PE: 49, range 0–100; MS: 43, range: 0–100) Cameron: (SGD: 93, range: 80–100; PE: 80, range 40–100; MS:76, range: 40–100) Andy: (SGD: 10, range 0–20; PE: 10, range, 0–20; MS: 0) Simon: (SGD: 9, range: 0–40; PE: 43, range: 0–100; MS: 3, range: 0–20) Nico: (SGD: 100; MS: 90, range: 80–100; MS: 90, range 60–100) Andrew: (SGD: 88, range: 40–100; PE: 70, range 0–100; MS: 0) Jimmy: (SGD: 82, range: 20–100; PE: 93, range 60–100; MS: 21, range: 0–100) Shane: (SGD: 83, range: 40–100; PE: 60, range 0–100; MS: 2, range: 0–20) Edward: (SGD: 82, range: 20–100; PE: 46, range 0–100; MS: 58, range: 0–100)	Henry: (SGD: 97, range: 80–100; PE: 100; MS: 100) Cameron: (SGD: 89, range: 70–100; PE: 85, range: 0–100; MS: 86, range: 0–100) Nico: (SGD: 100; PE: 100; MS: 100) Andrew: (SGD: 64, range: 0–100; PE: 60, range: 0–100; MS: 0) Jimmy: (SGD: 64, range: 20–100; PE: 95, range: 80–100; MS: 0) Shane: (SGD: 100; PE: 73, range: 60–100; MS: 0) Edward: (SGD: 100)	Henry: (SGD: 86, PE: 4, MS: 4) Cameron: (SGD: 60, PE: 23, MS: 16) Simon: (SGD: 56, PE: 8, MS: 3) Nico: (SGD: 100, PE: 0, MS: 0) Andrew: (SGD: 69, PE: 0, MS: 0) Jimmy: (SGD: 71, PE: 16, MS: 0) Shane: (SGD: 80, PE: 2, MS: 0) Edward: (SGD: 85, PE: 0, MS: 0)	DTT, prompting, reinforcement, time delay	No social validity	Conclusive

Table 2 (continued)

References	Operants	Name, age	Devices	Exp. design	Results acquired (%)	Results maintenance (%)	Results preference (%)	EBP	Quality indicators	Appraisal
Lorah (2016)	Mand, Tact	Aaron (12) Aiden (10) Gabe (9) Corey (8) Grace (9)	PE, SGD	ATD	Aaron: (SGD: 98, range: 80–100; PE: 96, range: 70–100) Aiden: (SGD: 97, range: 70–100; PE: 96, range 70–100) Gabe: (SGD: 93, range: 40–100; PE: 84, range 0–100) Corey: (SGD: 53, range: 30–100; PE: 32, range 10–100) Grace: (SGD: 85, range: 40–100; PE: 91, range 20–100)	N/A	Aaron: (SGD: 97) Aiden: (SGD: 100) Gabe: (SGD: 100) Corey: (None) Grace: (SGD: 97)	DTT; prompting, reinforcement, time delay	No baseline	Conclusive
Lorah et al. (2013)	Mand, Tact	Joel (5.5) Axel (4.3) Aaron (4.1) Peter (3.10) Rick: (5.11)	PE, SGD	ATD	Joel: (SGD: 77, range: 47–93; PE: 57, range 33–87) Axel: (SGD: 97, range: 93–100; PE: 83, range 60–100) Aaron: (SGD: 84, range: 80–87; PE: 55, range 26–92) Peter: (SGD: 66, range: 13–100; PE: 50, range 0–87)	Joel: (SGD: 100; PE: 90, range: 80–100) Axel: (SGD: 100; PE-86, range 60–100) Aaron: (SGD: 86, range: 73–100; PE: 64) Peter: (SGD: 15, range: 13–20; PE: 95, range: 87–100)	Joel: (SGD: 85, PE: 11) Axel: (SGD: 98, PE: 2) Aaron: (SGD: 94, PE: 4) Peter: (SGD: 78, PE: 4) Rick: (SGD, 15, PE: 89)	Prompting, reinforcement, time delay	No social validity	Conclusive

Table 2 (continued)

References	Operants	Name, age	Devices	Exp. design	Results acquired (%)	Results maintenance (%)	Results preference (%)	EBP	Quality indicators	Appraisal
McLay et al. (2015)	Mand, Tact, Intraverbal	Pene (7) Mika (8) Hemi (10.1) Afasa (5.2)	PE, MS, SGD	ATD	Pene: (SGD: 85, range 80–100; PE: 64, range 0–100; MS: 70, range 20–100) Mika: (SGD: 92, range 60–100; PE: 38, range 0–100; MS: 2, range 0–20) Hemi: (SGD: 55, range 0–100; PE: 48, range 0–100; MS: 63, range 0–80) Afasa: (SGD: 85, range 60–100; PE: 75, range 20–100; MS: 80, range 40–100)	Pene: (SGD: 64, range: 0–100; PE: 89, range: 0–100; MS: 4, range 0–10) Mika: (SGD: 97, range: 60–100; PE: 43, range: 0–100; MS: 0) Hemi: (SGD: 79, range 20–100; PE: 40, range: 0–100; MS: 0) Afasa: (SGD- 99, range: 80–100; PE: 50, range: 0–100; MS: 50, range: 50–100)	Pene: (SGD: 83, PE: 15, MS: 0) Mika: (SGD: 76, PE: 11, MS: 2) Hemi: (SGD: 71, PE: 7; MS: 8) Afasa: (SGD: 83, PE: 14; MS: 0)	DTT, prompting, reinforcement, time delay	No social validity	Conclusive
McLay et al. (2017)	Mand, Tact, Intraverbal	Manu (10) Lomu (5)	PE, MS, SGD	ATD within a MBD	Manu: (SGD: 69, range: 20–100; PE- 40% range, 0–100; MS: 11% range, 0–80) Lomu: (SGD: 50, range: 0–100; PE: 45% range: 0–100; MS: 11%, range: 0–60)	Manu: (SGD 0; PE: 20, range: 0–20; MS: 0) Lomu: (SGD: 67, range: 0–100; PE: 40, range: 0–80; MS: 0)	Manu: (SGD 58, PE 3, MS 0) Lomy: (SGD: 61, PE: 18, MS: 5)	DTT, prompting, reinforcement, time delay	No social validity	Suggestive
van der Meer et al. (2012)	Mand, Tact, Intraverbal	Joe (12) Sam (6) Nicky (13)	PE, MS, SGD	ATD within a MBD	Joe: (SGD: 92, range: 80–100; PE: 60, range: 30–100; MS: 50, range: 0–100) Sam: (SGD: 18, range: 0–70; PE: 50, range: 10–100; MS: 1, range 0–10) Nicky: SGD: 77, range: 10–100; PE: 96, range: 70–100; MS: 47, range: 10–90)	Joe: (SGD: 91, range: 60–100; PE: 93, range: 80–100; MS: 45, range: 30–65) Nicky: (SGD: 93, range: 90–100; PE: 100; MS: 23 range: 20–30)	Joe: (SGD: 61) Sam: (PE: 56) Nicky: (SGD: 75)	Prompting, reinforcement, task analysis, time delay	No social validity	Conclusive

Table 2 (continued)

References	Operants	Name, age	Devices	Exp. design	Results acquired (%)	Results maintenance (%)	Results preference (%)	EBP	Quality indicators	Appraisal
van der Meer et al. (2013)	Mand, Echoic, Intraverbal, Tact	Ian (10) Hannah (11)	PE, MS, SGD	ATD	Ian: (SGD: 66, range: 40–90; MS: 70, range: 40–100; PE: 71, range: 40–90) Hannah: (SGD: 36, range: 20–80; MS: 30, range: 5–70; PE: 54, range: 30–70)	Ian: (SGD: 82, range: 50–100; MS: 83, range: 80–90; PE: 100) Hannah: (SGD: 43, range: 20–50; MS: 32, range: 20–60; PE: 75, range: 60–100)	Ian: (SGD: 82, PE: 18) Hannah: (SGD: 28, PE: 72)	DTT, prompting, reinforcement, task analysis	No social validity, external validity	Suggestive
van der Meer et al. (2012)	Mand, Tact, Intraverbal	Jason (4) Jack (4) Ian (10) Hannah (11)	PE, MS, SGD	ATD within a MBD	Jason: (SGD: 92, range: 80–100; PE: 61, range: 30–100; MS: 47, range: 0–80) Jack: (SGD: 17, range: 0–70; PE: 52, range: 10–100; MS: 1, range: 0–10) Hannah: (SGD: 76, range: 10–100; PE- 96, range: 70–100; MS: 45, range: 10–90)	Jason: (SGD: 91, range: 60–100; PE: 93, range: 80–100; MS: 50, range 35–65) Hannah: (SGD 93, range: 90–100; PE: 100; MS: 27, range: 25–30)	Hannah: (PE: 69) Ian: (SGD: 85) Jack: (PE, 58, SGD: 30 Jason (SGD: 69)	DTT, prompting, reinforcement, time delay	No social validity, definitive parent participants, or IV information	Suggestive

This table shows the references from which the data were extracted from the 9 peer-reviewed studies which were examined

establish inclusion criteria. A total of nine studies were included in the final review, 10 studies were eliminated based on the research design used. Interobserver agreement (IOA) was 100%.

Coding Procedures

Prior to coding the articles, a codebook outlining each variable to extract and offering an operation definition for each coding option was developed, tested, and finalized by the authors. The codebook was developed as suggested by standards for completing systematic reviews (Higgins et al., 2019). Included articles were coded for the following information: citation, verbal operant evaluated, research design, device(s) used, participant information (age, sex, and diagnosis), quality indicators, evidence-based practice(s) used, visual appraisal, and overall appraisal. Like the search procedures, the articles were evaluated by three of the authors. Each author coded the articles independently before comparing their codes; any disagreements were resolved until IOA was 100% for each coding category. If a manuscript did not have sufficient information to complete a category, that category was designated as "not specified."

Verbal Operant

In addition to the citation and participant information, each article was coded for the verbal operant evaluated. Operational definitions were developed according to Skinner's (1957) analysis of verbal behavior and are included for each verbal operant. The definitions of verbal operants can be found in Table 1. For the majority of articles, multiply controlled verbal operants were indicated; this means that the operant under evaluation shared characteristics with more than one operant. For example, if the speaker "manded" for an item and that item was visible to the participant, that operant was scored as both a mand and tact, as it could not be determined what variable occasioned the operant, whether it be a motivating operation (MO) and the presence of the listener or the presence of the item alone. Further, if the participant "manded" for an item and the item was present, and the experimenter also stated, "What do you want?", the verbal behavior was scored as a mand-tact-intraverbal, as one could not be sure whether it was the MO or listener, the item, or the verbal stimulus of "what do you want?" that occasioned the verbal behavior.

Research Design

Studies were coded based on research design as outlined by Ledford and Gast (2018). Only studies that used alternating treatment designs or a variation of alternating treatment designs (i.e., with or without baseline) met criteria for inclusion in the review, as those studies used a design appropriate for detecting changes between two (or more) independent variables (Ledford & Gast).

AAC Mode

Each mode compared in the included studies was coded. An AAC mode was coded as "high-tech SGD" if it included a computer component and voice output (e.g., an AAC application ("app") on an iPad®). An AAC mode was coded as "low-tech picture exchange" if it used printed depictions (i.e., PECS or other picture-exchange procedures) that could be manually manipulated. An AAC mode was coded as "no-tech manual sign" if it required no material outside the user and utilized a system or language (e.g., American Sign Language) of manual signing.

Evidence-Based Practices

Evidence-based practices (EBP) were coded according to the National Clearinghouse on Autism Evidence and Practice (2020) definitions. The operational definitions for each of the used EBP were as follows.

Reinforcement An event, activity, or other circumstance occurring after a learner engages in a desired behavior that leads to the increased occurrence of the behavior in the future.

Prompting Verbal, gestural, or physical assistance given to learners to assist them in acquiring or engaging in a targeted behavior or skill. Prompts are generally given by an adult or peer before or as a learner attempts to use a skill.

Time Delay A process in which an activity or behavior is divided into small, manageable steps in order to assess and teach the skill. Other practices, such as reinforcement, video modeling, or time delay are often used to promote acquisition of the smaller steps.

Discrete-Trial Training Instructional process usually involving one teacher/service provider and one student/client and designed to teach appropriate behavior or skills. Instruction usually involves massed trials. Each trial consists of the teacher's instruction/presentation, the child's response, a carefully planned consequence, and a pause prior to presenting the next instruction.

Task Analysis In a setting or activity in which a learner should engage in a behavior or skill, a brief delay occurs between the opportunity to use the skill and any additional instructions or prompts. The purpose of the time delay is to allow the learner to respond without having to receive a prompt and thus focuses on fading the use of prompts during instructional activities.

Visual Analysis

For those studies that included both baseline and a treatment condition, graphical depictions for each participant in each treatment (i.e., SGD and/or MS and/or PE) were visually analyzed using an abbreviated visual analysis worksheet derived from Ledford & Gast (2018). This worksheet (see "Appendix") included a possible 13 yes/no questions that analyzed each visual depiction across level, trend, variability, overlap, and immediacy. A final determination of a functional relation was made based on the information collected from the worksheet and each participant and mode was given a score of present or not present in relation to the demonstration

of a functional relation. The results of this analysis can be found in Table 2 and are described in the results section. IOA was achieved for 30% of the participants by both the first and second author. Any disagreements were discussed until IOA reached 100%.

Summary Statistics

In addition to analyzing the visually graphed data, the authors extracted the raw data from graphs when possible. When those data were difficult to accurately extract, raw data were requested and obtained from the authors of papers included in this review. The raw data were then analyzed to calculate the mean and range of performance from each participant across the AAC modes compared in both the baseline (as applicable) and intervention phases. Then, the mean and range of performance for each AAC mode was compiled for all participants, creating an overall mean and range. This allowed for an understanding of overall how the individuals with ASD who participated in the included studies performed when using each AAC mode comparatively, both with and without instruction.

Effect Size Estimation

The raw data were used to develop effect size estimations for each participant when comparing the AAC mode conditions in each phase (i.e., baseline and intervention). Tau-U was chosen to estimate effect size given its validity when compared to visual analysis (Parker et al., 2011). This effect size estimation was calculated for each participant by comparing performance across AAC modes in both the baseline and intervention phases. Therefore, for each participant, Tau-U was calculated and reported by estimating the impact of each AAC mode in each study for each participant as compared to the other AAC modes both in baseline and intervention. This allowed for an estimation of the comparative effects of the different AAC modes on participant performance both prior to and after instruction.

To determine Tau-U effect size estimations, calculations were made by using a free online calculator (Vannest et al., 2016). After the effect sizes of each AAC mode for each participant were calculated in the baseline and intervention phases, guidelines were followed to interpret the effect sizes as indicative of strong, moderate, or weak or no effect (Parker et al., 2011).

Quality Indicators and Appraisal

Each manuscript was coded for quality indicators using the seven criteria outlined by Horner et al. (2005) (see Table 2). The first criteria were that the individual served as the unit of analysis and provided their own control. The second was that the description of the participants and setting were described in enough detail for replication. The third was that the dependent variable was operationally defined, measured repeatedly, included interobserver agreement data, and had social significance. The fourth criteria were that the independent variable was operationally

defined, actively manipulated, and included a fidelity measure. The fifth criteria were that experimental control was demonstrated through at least three repetitions of effect across three different points of time within a single participant or across three different participants. The sixth criteria were that the replications of experimental effect were across three different participants, conditions, and/or different measures of the dependent variable provided evidence of external validity. The last criteria were that social validity was demonstrated through the selection of the dependent variable with high social importance, an independent variable that can be applied across intervention agents, and that agents find the procedures acceptable, feasible, and effective. It should be noted that the quality indicator of baseline outlined by Horner et al. (2005) was not included in this study since the collection of baseline data is not a requirement for the demonstration of experimental effect (Ledford & Gast, 2018). Any study which had not included baseline data was marked not applicable. The results of the quality indictors yielded an overall appraisal for each study. A score of conclusive, preponderant, suggestive, or inconclusive was applied to each study as defined by Schlosser and Wendt (2008) and described below.

Conclusive The design provided experimental control, interobserver-agreement (IOA) was reliable, treatment integrity was solid; treatment outcomes are clearly from the independent variable (IV).

Preponderant Minor flaws with respect to the design, IOA, or treatment integrity—resulting in conclusion that treatment outcomes are more likely to have occurred as a result of the IV, yet conclusive.

Suggestive Several minor flaws or failed to provide treatment integrity data, leading to the conclusions that it was plausible, but not certain that the outcomes are the result of the IV.

Inconclusive There were significant flaws in the design (regardless of the IOA and treatment integrity) that precluded any conclusions regarding the impact of the IV.

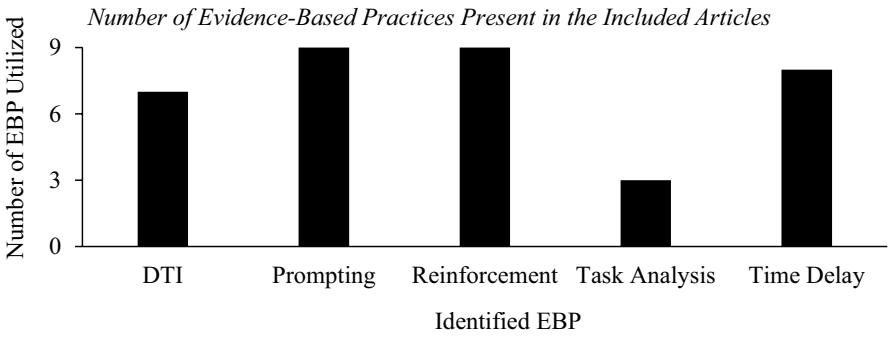

Fig. 1 Number of evidence-based practices present in the included articles. *Note* This figure depicts the number of evidence-based practices that were identified in the 9 peer-reviewed investigations which were analyzed

Table 3 Identified quality indicators during baseline

Modality	Mean	SD	Range
SGD	60.71	37.10	0–100
PE	51.75	39.39	0–100
MS	26.18	36.29	0–100

This table shows the statistics regarding the extracted intervention data from the participants

Table 4 Identified quality indicators during baseline

Modality	Mean	SD	Range
SGD	10.08	22.71	0–100
PE	0.72	3.60	0–30
MS	2.73	15.78	0–100

This table shows the statistics regarding the extracted baseline data from the participants

Results

Results of the PRISMA search and article extraction are included in Fig. 1. A total number of nine full-text publications were included in the final review. Table 2 outlines the intervention studies, their participants, the EBPs used, the nature of the communication measured, the modes of AAC compared, baseline performance across AAC modes, intervention performance across AAC modes, preferences across AAC modes, a visual appraisal, and a quality appraisal. Tables 3 and 4 provide information on effect size estimations across AAC modes.

Participant Characteristics

The nine studies included a total of 36 participants with ASD. The participants were all children with a *mean age* of *seven,* in which the youngest participants were three while the oldest participant was 13.

EBPs Used in Intervention

All of the included studies used one of the previously described EBP (see Methods). Of the nine identified studies, reinforcement and prompting were used in all studies; time delay was used in eight studies; discrete-trial training was used in seven studies; finally, task analysis was used in three studies (see Fig. 1). All of the EBPs identified were used across all modes included in the comparative analysis, unless otherwise specified.

Verbal Operant Nature of Communication Measured

In three studies, the communication behavior measured for comparison across AAC modes constituted a mand and a tact (Agius & Vance, 2016; Lorah, 2016; Lorah

et al., 2013). In five studies, the communication measured was a mand, tact, and intraverbal (Couper et al., 2014; McLay et al., 2015, 2017; van der Meer et al., 2012a; b). Last, the communicative behavior of concern from one study constituted a mand, tact, intraverbal, and echoic (van der Meer et al., 2013).

Modes of AAC Compared

High-tech SGDs were compared to both no-tech manual sign and low-tech picture exchange in 6 studies (Couper et al., 2014; McLay et al., 2015; McLay et al., 2017; van der Meer et al., 2012a; b; 2013). High-tech SGDs were compared to low-tech picture exchange alone in three studies (Agius & Vance, 2016; Lorah, 2016; Lorah et al., 2013). Reported results derive from all AAC modes compared for any participant.

Baseline Performance Across AAC Modes

When using a high-tech SGD, participants across all studies demonstrated a *mean baseline performance* level of *11.4%* (SD = 23.9; range: 0–100%) overall. When using low-tech picture exchange, participants demonstrated a *mean baseline performance* level of *0.8%* (SD = 3.8; range: 0–30%) overall. When using no-tech manual sign, participants demonstrated a *mean baseline performance* level of *2.8%* (SD = 16.1; range: 0–100%) overall.

Intervention Performance Across AAC Modes

When using a high-tech SGD, participants across all studies demonstrated a *mean intervention performance* level of *63.8%* (SD = 34.8; range: 0%-100%) overall. When using low-tech picture exchange, participants demonstrated a *mean intervention performance* level of *53.1%* (SD = 38.1; range: 0%-100%) overall. When using no-tech manual sign, participants demonstrated a *mean intervention performance* level of *22.9%* (SD = 33.5; range: 0%-100%) overall.

Effect Size Estimation

According to effect size estimations through Tau-U calculations, five participants in baseline (i.e., in the absence of instruction) experienced a moderate (n = 3) or strong (n = 2) positive effect of high-tech SGDs compared to picture exchange while two participants experienced a strong positive effect of picture exchange as compared to SGD use. Seven participants experienced a moderate (n = 3) or strong (n = 4) positive effect of high-tech SGDs as compared to manual sign while one participant experienced a strong positive effect of manual sign as compared to SGD use. Two participants experienced a strong (n = 2) positive effect of picture exchange compared to manual sign while one participant experienced a strong (n = 1) positive effect of manual sign compared to picture exchange.

According to Tau-U effect size estimations in intervention (i.e., during instruction), three participants experienced a strong (n = 1) or moderate (n = 2) positive effect of picture exchange compared to an SGD while two participants experienced a moderate (n = 2) positive effect of SGD as compared to picture exchange. Ten participants experienced a moderate (n = 6) or strong (n = 4) positive effect of SGD use as compared to manual sign. Eight participants experienced a strong (n = 3) or moderate (n = 5) positive effect of picture exchange as compared to manual sign. See Tables 2 and 3 for an outline of effect size estimations in the baseline and intervention phases.

Preferences Across AAC Modes

When preference was assessed, most participants (n = 31) preferred interacting using a high-tech SGD while only four participants preferred interacting using low-tech picture exchange. No participants preferred interacting using no-tech manual sign. Figure 2 illustrates participant preference across AAC modes.

Visual Appraisal

The results of the visual appraisal can be found in Table 2. Within the Agius and Vance (2016) evaluation, a functional relation was indicated for three participants

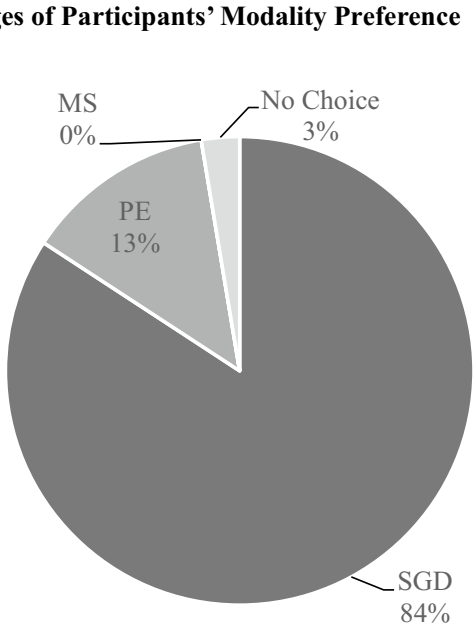

Fig. 2 Percentages of participants' modality preference. *Note* This figure depicts the modality preference from the participants in the nine studies examined

across all three modes. Among the nine participants in the Couper et al. (2014) evaluation, a functional relation appeared in four out of nine (44%) participants in MS; six out of nine (67%) in PE; and seven out of nine (78%) for SGD. Within the Lorah et al. (2013) evaluation, a functional relation was indicated for all five participants across both PE and the SGD. However, the Lorah (2016) study was not included in the visual appraisal analysis, as the study did not include a baseline condition. Furthermore, the McLay et al. (2015) evaluation indicated a functional relation among the three out of four (75%) participants for MS; two out of four (50%) participants for PE; and four out of four (100%) participants for SGD. For the McLay et al. (2017) evaluation, a functional relation was indicated for one of two (50%) participants from the PE and SGD participants, but none of the MS conditions. Within the van der Meer et al. (2012a) evaluation, a functional relation was indicated for one of two (50%) participants across all three modes. For the van der Meer et al. (2012b) evaluation, a functional relation was indicated for three of the four (75%) participants for MS; two of the four (50%) participants for PE; and all four (100%) of the participants for the SGD. Finally, for the van der Meer et al. (2013) evaluation, a functional relation was indicative for 0% of the participants using MS; and one of the two (50%) participants for PE and the SGD.

Quality Indicators and Appraisal

Of the nine studies included in the review, only two included a formal measure of social validity within their procedures (Agius & Vance, 2016; Lorah, 2016). One study failed to include sufficient replications of experimental effects within their research design (McLay et al., 2017) while another failed to completely describe their participants or provide sufficient detail on the IV for replication purposes (van der Meer et al., 2012b).

In terms of the appraisal, six studies were ranked as conclusive (Agius & Vance, 2016; Couper et al., 2014; Lorah et al., 2013; Lorah, 2016; McLay et al., 2015; van der Meer et al., 2012a); three studies were ranked as suggestive (McLay et al., 2017; van der Meer et al., 2012b; van der Meer et al., 2013); and none of the included studies were ranked as preponderant or inconclusive.

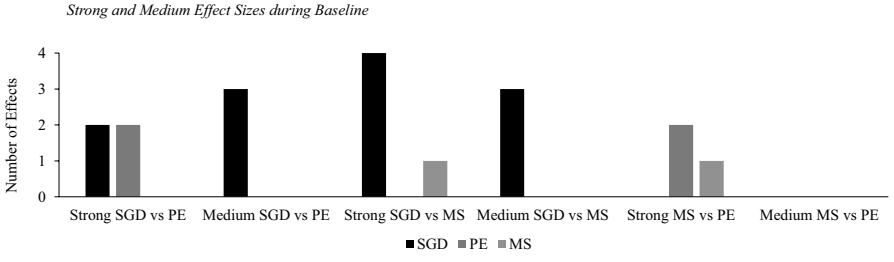

Fig. 3 Results of the article extraction procedure

Discussion

The results of the PRISMA search and article extraction are included in Fig. 3. This review systematically explored AAC intervention research focused on children with ASD in which communication using high-tech mobile technology outfitted to function as SGDs were compared to other AAC modes. Included studies compared high-tech SGDs to low-tech picture exchange and no-tech manual sign. Throughout the nine included and examined articles, a total of 36 participants with ASD were evaluated.

Overall, the participants' performance during the baseline phase within the included studies indicated that, without instruction, children with ASD communicate with limited success across AAC modes. This finding is consistent with the sentiment that providing access to an AAC technology alone is not enough to allow for effective communication (Ganz, 2015). However, in the absence of instruction, effect size estimations indicated that more participants benefited from SGDs when compared to either PE or MS (see Table 3 and Fig. 4). This finding supports previous literature questioning the sentiment that high-tech SGDs are more difficult to use than low-tech AAC options (Hoffman et al., 2017).

The participants' performance during instruction (i.e., in the intervention phase) was higher than baseline performance overall across all three AAC modes. This finding is consistent with previous literature highlighting the importance of effective instruction in AAC intervention (Ganz, 2015). All intervention studies utilized at least three instructional strategies determined as evidence based for children with ASD. The observed increase in verbal behavior through AAC modes following instruction support these as evidence-based instructional practices within the EBP of AAC intervention for children with ASD (Steinbrenner et al., 2020). Effect size estimations indicated variable comparative effects of high-tech SGDs and low-tech picture exchange across participants (see Fig. 5 and Table 4). However, no participants demonstrated moderate or strong benefits from MS use as compared to either high-tech SGDs or low-tech picture exchange. Importantly the vast majority of participants indicated a preference for communicating high-tech SGDs; no participants indicated a preference for MS (see Fig. 2). These results were consistent across past studies that included participant preference (e.g., b; Couper et al., 2014; Lorah, 2016; Lorah et al., 2013; McLay et al., 2015, 2017; van der Meer et al., 2012a)

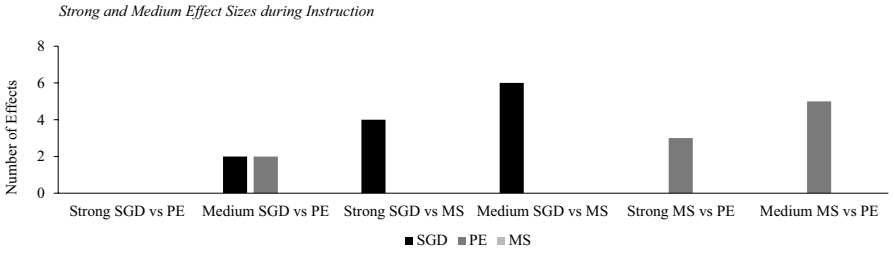

Fig. 4 Strong and medium effect sizes during baseline. *Note* This figure depicts the strong and medium effect sizes which occurred during the baseline condition

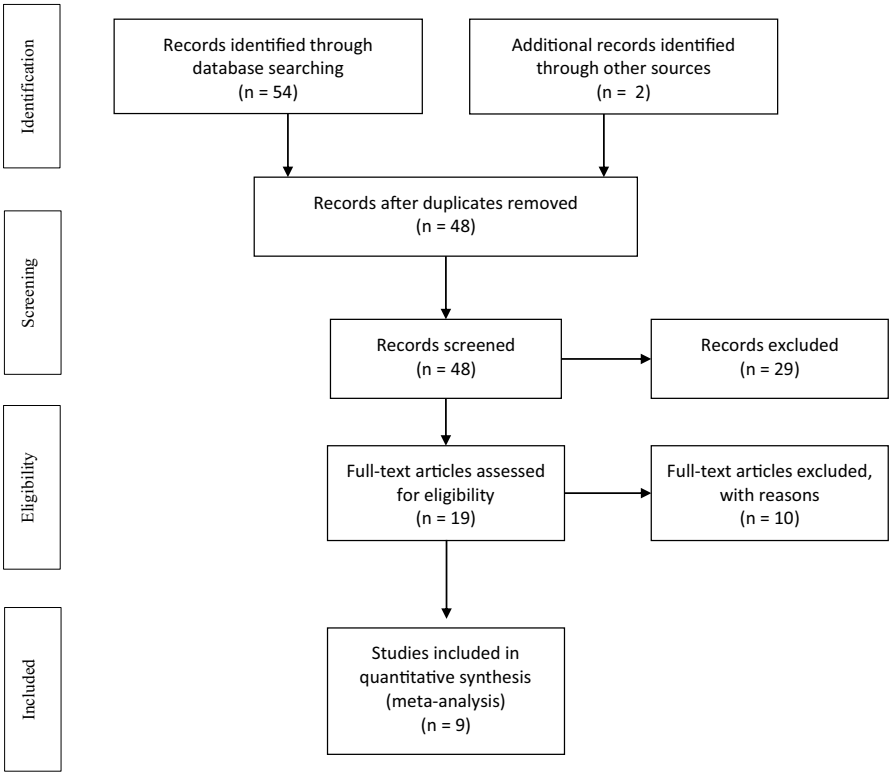

Fig. 5 Strong and medium effect sizes during instruction. *Note* This figure depicts the strong and medium effect sizes which occurred during the intervention condition

and are compelling given the varying preferences typically seen in individuals with ASD.

Implications for Practice

Taken as a whole, the results from this study suggest that practitioners should consider use of mobile technology with AAC apps as high-tech SGDs in AAC intervention for children with ASD given the strong preference pattern observed for the technology as well as the overall higher performance level both with and without instruction when compared to low-tech picture exchange and no-tech manual sign. However, regardless of the AAC mode implemented, practitioners should use a combination of EBPs in instruction given the overall benefits of evidence-based instruction on communication observed in this study across all AAC modes. When evaluating different AAC modes for use with an individual with ASD, this review

suggests practitioners should evaluate preference as well as performance. Preference can have a strong impact on learning overtime. Further, this review suggests that even when the comparative influence of different AAC mode on performance is unclear, the influence of different modes on preference be pronounced.

Implications for Research

Findings form this review indicate that more comparative AAC intervention is needed that is focused on individuals with ASD given the discrepancy between the number of articles that qualified for inclusion in this review as compared to the number of articles qualifying for inclusion in recently published systematic reviews on AAC intervention research for individuals with ASD more broadly (e.g., Morin et al., 2018). Comparative AAC intervention research focused on adolescents and adults with ASD is also needed, given that the oldest participant in this study was 13 years old. In 2017, Holyfield and colleagues published a systematic review of AAC intervention research for adolescents and adults with ASD and found only 14 publications focused on AAC intervention research for individuals from these populations, though none of those studies included comparative research that met criteria for this review. In fact, none of the included studies in this review contained only adolescent participants, and no adults or adolescents over 13 years old with ASD participated in any of the identified comparison studies.

Additionally, this review revealed that all AAC intervention research comparing high-tech SGDs to other AAC modes has focused on manding, which is consistent with previous literature suggesting a hyper-focus on the communicative function of requesting in AAC intervention research for individuals with ASD (Holyfield et al., 2017; Logan et al., 2017). Communication for social interaction is a primary limitation for individuals with ASD (APA, 2013). Moreover, important factors not clear while measuring mands to a researcher may have major differential impacts on the viability and utility of AAC modes (e.g., the perceptions of peers toward the different modes; Lorah et al., 2021). Therefore, comparative research during highly meaningful social interactions (e.g., when interacting with peers), should be a top priority for the future.

Limitations

A major limitation of the current review is that only nine studies were identified that met criteria for inclusion and that for almost all studies, the level of evidence was not conclusive. Further, due to the single-subject designs utilized in the studies, a limited number of participants (n = 36) were included, thus limiting the external validity in which strong conclusions can be drawn about the generalizability of the findings from this review to children with ASD.

This review was also limited by its focus generally on broad distinctions in AAC modes. Even within the AAC mode categories explored in this study (i.e., SGD, picture exchange, manual sign), great variation exists between different options. Different SGDs, for instance, can vary based on factors including organizational structure, representation, and vocabulary available. These differences stand to deeply influence the efficacy of AAC intervention even when the AAC modes containing these differences are the same (Light et al., 2019). In fact, recent research has evaluated the comparative effects of different representation options across high-tech AAC modes that are otherwise identical and found it to be an important factor on transparency and learnability (e.g., Holyfield, 2021; Schlosser et al., 2019). Thus, the conclusions that can be drawn from this study are severely restricted by the lack of reporting on differences in factors within and between AAC modes that could have influenced their comparative effectiveness.

Also, the review did not evaluate comparative differences related to generalization and maintenance despite this information being included in several of the studies reviewed. A lack of reporting on this information further limited the external validity of the conclusions drawn.

As is the case with any systematic literature review, there exists the possibility that a study was overlooked within the search procedures. That said, the researchers took every precaution to ensure that this did not happen within the methods of the current systematic search criteria.

Finally, the findings from this review are limited by any bias created inadvertently by the specific decisions made around article identification and inclusion as well as data coding and analysis. Notably, an important bias is publication bias (Vevea et al., 2019) given only studies published in peer-review journals were included in this investigation.

Conclusion

This systematic review revealed the limited research available to date comparing AAC modes for use in intervention with individuals with ASD. The review revealed no published research systematically comparing AAC modes for any individuals with ASD over the age of 13. Continued empirical investigation is urgently needed to provide practitioners with clear guidance around AAC decision-making for individuals with ASD and limited speech. Until that time, this review suggested that practitioners should consider prioritize high-tech SGD modes in AAC intervention for children with ASD. With without and with instruction, participants overall appeared to communicate the most using high-tech SGDs. Further, the vast majority of participants in the included studies indicated a preference for communicating with high-tech SGDs. Given the combination of higher performance and higher preference revealed in this review, this systematic review revealed the value of implementing high-tech SGDs in AAC intervention for individuals with ASD.

Appendix

Visual Analysis Worksheet

Researcher initials:
IOA:
Reference:
Participant:
Device:

Characteristic	Questions	+	−	N/A
Level	Is a consistent level established in each condition prior to condition change?	Yes	No	
	Is there a consistent level change between conditions, in the expected direction?	Yes	No	
Trend	Are unexpected trends present that make determination of behavior change difficult?	No	Yes	
	Is there a consistent change in trend across conditions, in the expected direction?	Yes	No	
Variability	Does unexpected variability exist in one or more conditions?	No	Yes	
Consistency	Are data within conditions and changes between conditions consistent?	Yes	No	
	If changes are inconsistent with regard to level, trend, or variability, was it expected?	Yes	No	
Overlap	Are data overlapping between conditions?	No	Yes	
	If overlapping, does the degree of overlap improve overtime?	Yes	No	
	Is overlap consistent across comparisons?	Yes	No	
	Was overlap expected a priori?	Yes	No	
Immediacy	Are changes between tiers immediate, in the intended direction?	Yes	No	
	If no, are delays in changes consistent across tiers?	Yes	No	
Total:				

What is your determination regarding the presence of a functional relation?	Present	Not Present

Taken from Ledford and Gast (2018)

Declarations

Ethical Approval This study did not involve human or non-human participants and therefore, ethical approval was not required.

Informed Consent This manuscript did not include human participants so informed consent was not obtained.

Conflict of Interest The authors declare no conflict of interests.

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