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Effects of Interventions Involving Tablet-Based Speech-Generating Devices for Individuals with ASD: A Meta-analysis

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Abstract

The purpose of this review was to assess the effectiveness of tablet-based speech-generating devices (SGDs) in improving communication skills for individuals with autism spectrum disorder (ASD). A total of 31 single-case design intervention studies involving 84 individuals with ASD were reviewed and included in the analysis. We calculated Tau-U to evaluate the impact of interventions involving tablet-based SGDs on four different communication responses: specifically, mands, intraverbals, tacts, and vocalizations. To explore potential moderating variables for mand outcomes, we used the Kruskal–Wallis one-way test. The analysis revealed that interventions utilizing tablet-based SGDs led to improvements in communication responses. Specifically, large to very large changes were observed in mand and intraverbal responses, whereas moderate changes were noted in tact responses and vocalizations. The findings of this review underscore the potential of tablet-based SGDs in enhancing communication among individuals with ASD. We discuss the findings and provide implications for future research and practice.

Keywords Autism spectrum disorder · Communication · Speech-generating devices · Verbal operants

Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental condition characterized by persistent limitations in social communication and interaction, as well as restricted and repetitive patterns of behavior, interests, or activities (American Psychiatric Association, 2013). Communication support needs are among the core characteristics of ASD and can have a profound impact on individuals' daily functioning and quality of life (Estes et al., 2011; Liptak et al., 2011; McNaughton et al., 2012). It has been estimated that about 30% of individuals with ASD may not have intelligible functional speech (Wodka et al., 2013) and, therefore, augmentative and alternative communication (AAC) may be necessary to promote communication. AAC is a set of tools used to supplement or replace speech for individuals with complex communication needs (Schlosser & Wendt, 2008).

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There are several types of AAC, including unaided AAC and aided AAC (Mirenda, 2003). Unaided AAC includes options that do not require equipment such as gestures and sign language, whereas aided AAC includes options that require equipment and can be classified as low-tech (e.g., picture exchange) and high-tech (e.g., speech-generating devices [SGDs]). SGDs are electronic devices that generate synthesized or digitized speech. Schlosser (2003) noted that SGDs can address different communication needs, such as making requests, naming items, and expressing opinions or answering questions. Skinner (1957) categorized these types of communicative actions as verbal operants, specifically mands, tacts, and intraverbals, respectively.

Recently, electronic tablets (e.g., Samsung, Apple iPads) have been used with communication applications (apps) as SGDs, allowing for a more portable and user-friendly option for individuals with ASD to access AAC (Lorah et al., 2022b). These devices have the added benefit of being highly customizable, providing users with the ability to personalize their communication systems and adapt to changing needs over time. Additionally, tablets are often less stigmatizing than traditional AAC devices, making them a more socially acceptable option for individuals with ASD to use in various settings (Lorah et al., 2022b). As such, the use of tablets

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and communication apps as SGDs has become increasingly popular in recent years and warrants further investigation through meta-analytic techniques.

Recent meta-analyses and systematic literature reviews have shed light on the effectiveness of SGDs in supporting communication and language development for individuals with ASD. Tincani et al. (2020) conducted a systematic review of verbal operants in SGD research, focusing on research that utilized Skinner's (1957) analysis of verbal behavior. The authors analyzed 56 studies and found that SGDs were effective in increasing a variety of verbal operants, including mand, tact, and intraverbal responses, among individuals with ASD and other developmental disabilities. Another recent systematic review focused on the use of SGDs to support communication and language development for individuals with ASD (Lorah et al., 2022b). The authors reviewed 38 studies and found that SGDs were effective in improving communication outcomes of individuals with ASD. The authors also identified several evidence-based instructional practices that were incorporated into SGD-based interventions including prompts, discrete trial training, naturalistic teaching, peer-mediated instruction, and reinforcement. Although both systematic reviews provided valuable support for SGDs to promote the communication skills of individuals with ASD, neither review analyzed potential moderators that might influence the effectiveness of SGDs for individuals with ASD.

Similarly, Morin et al. (2018) conducted a systematic quality review of high-tech AAC interventions as an evidence-based practice across 23 studies. Although their review examined a range of SGDs for individuals with ASD and intellectual disability, the present meta-analysis aims to build on their work by focusing on up-to-date tablet-based SGDs for individuals with ASD specifically. Additionally, although Morin et al. focused on the quality of studies, the present meta-analysis also examines the outcomes of tablet-based SGDs across specific verbal operants of individuals with ASD, as well as potential moderators of these outcomes. By specifically examining the effectiveness of interventions utilizing tablet-based SGDs, this meta-analysis provides a more targeted and focused approach to evaluating the use of tablet-based SGDs in the context of supporting the communication needs of individuals with ASD.

Muharib and Alzrayer (2018) conducted a meta-analysis specifically focused on the use of high-tech SGDs as an evidence-based practice for children with ASD ages 0 to 8 years. Although their review examined the overall effectiveness of high-tech SGDs on communication outcomes, the present meta-analysis aims to expand on their work by examining the specific effects of interventions involving up-to-date tablet-based SGD on different verbal operants (i.e., mands, tacts, intraverbals) as well as vocalizations and potential moderators of the effects of tablet-based SGD interventions for individuals with ASD without age restrictions.

Recent systematic literature reviews and meta-analyses have provided valuable insights into the effectiveness of SGDs in supporting communication and language development for individuals with ASD. However, there is still a need for a comprehensive meta-analysis that focuses specifically on the use of tablet-based SGDs to increase verbal operants for individuals with ASD. Previous literature reviews (Lorah et al., 2022b; Morin et al., 2018; Muharib & Alzrayer, 2018; Tincani et al., 2020) provided valuable contributions to the literature, but their focus on broader areas of AAC technology (including outdated technology) or diagnosis (ASD, intellectual disability, developmental delay), and the lack of analyses of potential moderators suggest that a more focused examination of tablet-based SGDs is needed.

Thus, this meta-analysis aims to fill this gap by systematically reviewing the literature on the use of tablet-based SGDs to increase the communication skills of individuals with ASD. In the meta-analysis, we examined the characteristics of studies using up-to-date tablet-based SGDs to increase communication, the quality of these studies, and the overall estimated effects of these interventions on communication outcomes of individuals with ASD. Additionally, the meta-analysis explored potential moderators of these estimated effects, such as age, diagnosis, communication levels, prior experience with SGDs, setting, interventionist, and context. By synthesizing the available literature on SGD interventions for individuals with ASD, this meta-analysis contributes to a better understanding of the potential benefits of tablet-based SGDs in supporting communication and language development for individuals with ASD. Specific research questions included:

(a) What are the characteristics of studies using tablet-based SGDs to increase mand, tact, and intraverbal responses and vocalizations of individuals with ASD?
(b) What is the quality of studies involving the use of tablet-based SGDs for individuals with ASD based on the CEC (2014) standards?
(c) What are the overall estimated effects of tablet-based SGDs on mand, tact, and intraverbal responses and vocalizations of individuals with ASD?
(d) Do age, diagnosis, communication levels, prior experience with SGD, setting, interventionist, and context moderate the effects of tablet-based SGDs on mand, tact, and intraverbal responses and vocalizations of individuals with ASD?

Method

Search Procedure

We searched EBSCO, PsycInfo, ERIC, MedLine, and ProQuest Dissertations and Theses Global to locate studies that incorporated the use of an SGD using the following three categories of search terms: (a) SGD (keywords: speech-generating device, SGD, AAC, augmentative and alternative communication, iPad, tablet, high-tech), (b) autism (keywords: autis* OR ASD), and (c) verbal behavior (keywords: mand*, fill-in, tact*, intraverbal, verbal behavior, verbal operant, request, label, comment, answer question). The searches were restricted to studies published since 2010 in English. We restricted the publication date because iPads were released in 2010 for the first time (Tincani et al., 2020) and to focus only on devices that are up to date. It is important to note that we did not limit the searches to iPads; however, because iPads were the first tablets introduced in the market, we restricted the search to 2010 up to the present date. We searched published and unpublished studies (e.g., dissertations) to reduce the threat of publication bias. We completed additional searches by (a) reviewing the reference lists of six recently published literature reviews on SGDs (i.e., Logan et al., 2022; Lorah et al., 2022a, 2022b, 2022c; Morin et al., 2018; Tincani et al., 2020) and (b) reviewing the reference lists of all included studies identified via the online database search. Searches concluded in February of 2023 and resulted in a total of 5410 articles (5405 from online database searches and five from ancillary searches) after removing duplicates. See Fig. 1 for a flowchart.

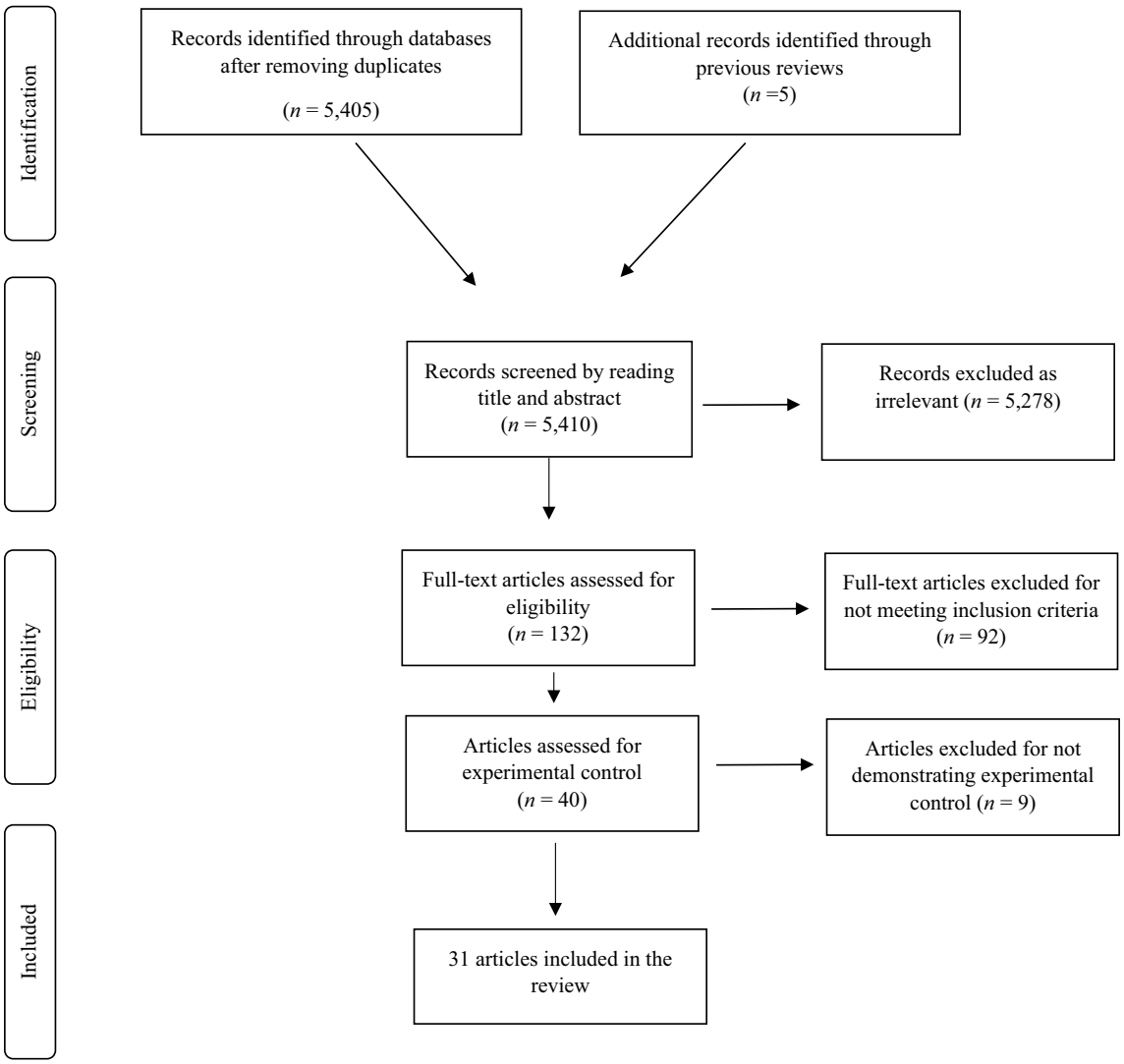

Fig. 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) summary of article extraction process

Inclusion and Exclusion Criteria

We evaluated each study against the following inclusion criteria: (a) included at least one participant with ASD; (b) was an experimental study (single-case research designs or experimental group designs); (c) involved teaching individuals with ASD to use a tablet-based SGD to mand, tact, or engage in an intraverbal response; (d) involved an SGD that was a touchscreen tablet (e.g., iPad, Samsung) and was not outdated (i.e., not available on the market as a new product such as iPods); and (e) involved behavioral interventions that were intended to promote communication via SGD.

We excluded studies from the review when they met at least one of the following exclusion criteria: (a) none of the participants had a diagnosis of ASD, (b) was not an experimental study, (c) an SGD was outdated (e.g., iPod) or not indicated, (d) the dependent variable combined multiple communication skills in one dependent variable (e.g., communicative acts that included mands, comments, head nods, gestures) because this would not allow for categorizing the dependent variable under one specific verbal operant (however, if a study included more than one verbal operant but each was its own dependent variable [e.g,. requesting preferred items, tacting, answering personal questions], then the study was included), and (e) when the study involved a tablet-based SGD but the intervention was programmed to decrease SGD use and increase vocalizations only (e.g., Muharib et al., 2021a). Although this is may be the ultimate goal for some individuals with ASD (i.e., transitioning from SGD use to vocal communication), we excluded these studies because our primary aim was to determine the effects of SGDs and behavioral strategies that were intended to increase SGD-based communication. We reviewed the abstracts of the 5410 studies to identify those that were not intervention-based (e.g., literature reviews) or not relevant to the current study (e.g., studies on different topics). This led to the exclusion of 5278 studies. We then accessed the full text of the remaining 132 studies to evaluate against our inclusion criteria. This resulted in 40 potentially relevant studies.

Next, we evaluated the experimental control of each of the 40 studies. Because common published quality evaluation tools (e.g., Council for Exceptional Children [CEC], 2014; Horner et al., 2005; Kratochwill et al., 2013) emphasize the importance of establishing experimental control, we only included studies that attempted to demonstrate experimental control in our analyses. Because all 40 studies used a single-case design, a study had to show at least three attempts to show an intervention effect. Thus, we excluded studies that used a multiple baseline design (or variations thereof) with fewer than three tiers (e.g., a multiple baseline across two participants). If a study used an alternating treatment design, then the study had to show some separation in the data paths to show experimental control. After evaluating the 40 studies, we excluded nine studies for not demonstrating experimental control (see Fig. 1 for a flow chart).

Data Extraction and Coding

We extracted descriptive information across each of the 84 participants represented in the 31 included studies in terms of (a) participant characteristics (i.e., age, sex, race/ethnicity, diagnosis, reported severity of ASD, communication level, prior experience with SGD); (b) settings (i.e., clinic, home, school); (c) interventionists (i.e., researcher, practitioner, parent); (d) components of the behavioral intervention (e.g., reinforcement, prompts) and context (i.e., discrete trial training [DTT] or naturalistic); (e) primary verbal operant addressed through SGD-based intervention (i.e., mand, tact, interverbal) and vocalizations if applicable; (f) the communication app in the device (e.g., Proloqu2Go, GoTalk Now); and (g) whether social validity, generalization, or maintenance were collected for each participant. We coded data using "1" to indicate the variable was relevant to the participant or "0" to indicate the variable was not relevant to the participant. When a study did not clearly provide specific information regarding those variables (e.g., communication level, severity of ASD), we coded the variable as "cannot determine." In addition to coding those aforementioned variables, we descriptively extracted information from each article about the research design used (e.g., multiple baseline across behaviors, multiple probe across participants) and types of preference assessments completed if applicable (e.g., reports, multiple stimulus without replacement, paired choice).

Participant characteristics For the age group variable, we coded each participant as early childhood (younger than 5 years old), middle childhood (5–12 years old), adolescence (13–17 years old), and adulthood (18 years old and older). For the sex variable, we coded each participant as a male or female based on what was reported in the original study. For the race/ethnicity variable, we coded each participant as White, Black, Latino, Mixed race, Asian, Pacific, Native American, or not reported. For the diagnosis variable, we coded each participant as diagnosed with ASD only (e.g., autism, autistic disorder, pervasive developmental disorder not otherwise specified) or ASD+. This reflects participants that had a diagnosis of ASD and another diagnosis such as intellectual disability, speech impairment, or hearing impairment. For the severity of ASD, we coded each participant as mild, moderate, or severe based on what was reported in the original study. For the communication level variable, we coded each participant as communicating using prelinguistic behaviors (e.g., pointing, leading an adult), one-word utterances (vocally or using the SGD), or full sentences (vocally or using SGD; Muharib et al., 2021b). For the prior

experience with SGD, we coded each participant as (a) a user if they were current users of an SGD or had an experience with an SGD prior to being a participant in the original study or (b) new to SGD if they never had an experience with any SGD.

Settings We coded three variables related to settings. For settings, we coded whether a participant received the intervention in a clinic, school, or home setting.

Interventionists For interventionists, we coded whether the intervention was delivered by a researcher, parent, or practitioner. A practitioner was considered someone already working with the participant and who was not part of the research team (e.g., behavioral therapist, speech-language pathologist, teacher, paraprofessional).

Components of the intervention and context We coded five variables related to the components of the intervention. These were the use of prompts, prompt delay, reinforcement, behavior chain interruption strategy, and backward chaining. Under each variable, we coded whether it was part of the behavioral intervention for each participant. For the intervention context, we coded whether the intervention was delivered in a DTT format or was embedded in naturally occurring activities for each participant.

Primary verbal operant We coded each participant's primary verbal operant addressed through the SGD-based intervention (i.e., mand, tact, intraverbal). For the majority of participants, verbal operants were multiply controlled. For example, when a participant responds "I want an apple" after a practitioner asks "what do you want?" and the apple is present, the verbal operant is controlled by an establishing operation (assuming the participant was deprived of food), a non-verbal stimulus (the apple), and a verbal stimulus (what do you want?). However, the primary verbal operant in this case is a mand. In addition to primary SGD-based verbal operants, we also coded whether data on vocalizations were collected. This was to determine whether the use of SGD could increase or decrease vocalizations of individuals with ASD.

Communication app in the device We coded the communication app that was used by each participant. Examples included Proloqu2Go, GoTalk Now, and LAMP.

Social validity, generalization, and maintenance We coded whether social validity data were gathered. Additionally, we coded whether generalization or maintenance were collected and graphed.

CEC Standards

Because all included studies used a single-case design, we only applied the CEC (2014) quality indicators applicable to single-case design studies. Thus, we evaluated each study against 22 quality indicators under eight categories (i.e., context and setting, participants, intervention agent, description of practice, implementation fidelity, internal validity, dependent variable, visual analysis).

Interrater Reliability

The third author served as a secondary coder for interrater reliability (IRR) purposes. Training the third author entailed oral and written explicit operational definitions of the inclusion criteria, coding variables, CEC quality indicators as well as examples and non-examples for each of the aforementioned items. We calculated IRR item-by-item and divided the number of agreements by the number of agreements plus disagreement and multiplied by 100 to obtain a percentage of agreement.

Inclusion of the studies The first author assigned 40 randomly selected studies of the 132 full texts (30.3%) to the third author. The IRR result for the inclusion of the studies was 100%.

Data Extraction and coding The first author assigned 31 randomly selected participants (36.9%) for data coding to the third author. The IRR result for data coding was 100%.

CEC quality indicators The first author assigned 10 randomly selected articles (32.2%) for CEC quality indicators to the third author. The IRR result for data coding was 100%.

Intervention Effect Estimation and Moderator Analyses

We examined the effect of interventions involving tablet-based SGDs on communication outcomes of individuals with ASD and whether certain variables moderated these outcomes. To estimate intervention effect, we calculated Tau-U (Parker et al., 2011) for each participant across communication measures (i.e., SGD-based mands, tacts, and intraverbals, vocalizations). Tau-U is a nonoverlap index that takes into account undesirable trends in baseline and has outperformed other nonoverlap indices for estimating intervention effect in single-case research contexts (Parker et al., 2011). Tau-U can be interpreted in the following way: < 0.20: small change, 0.20–0.60: moderate change, 0.60–0.80: large change, and > 0.80: large to very large change (Vannest et al., 2016). To calculate Tau-U, we initially extracted numerical values from graphic displays of participant data using WebPlotDigitizer (Rohatgii, 2018). Once numerical data values were obtained, we calculated Tau-U using a free online Tau-U calculator (Vannest et al., 2016). During this process, we corrected for baseline when monotonic trends were present, contrasted baseline and intervention data ($n = 99$ for mands, $n = 25$ for tacts, $n = 46$ for intraverbals, $n = 11$ for vocalizations), selected weighted Tau-U outcomes to account for complex research designs (Parker et al., 2011), and combined these weighted Tau-U

outcomes to provide aggregated Tau-U data for each participant and communication measure.

To explore whether certain variables moderated intervention outcomes, we conducted nonparametric moderator analyses across variables with eight or more cases (Walker & Snell, 2013). As such, we only were able to conduct moderator analyses for mand outcome measures across the following variables: age (early childhood and middle childhood), diagnosis (ASD and ASD+), communication levels (prelinguistic and one word), prior experience with SGD (current user and new user), setting (clinic and school), interventionist (researcher and practitioner), and context (DTT format and embedded). Using SPSS 28.0 for Mac, we applied the Kruskal–Wallis one-way analysis of variance test to determine whether significant differences existed for eligible variables based on Tau-U.

Results

Descriptive Findings

Descriptive findings of study characteristics are presented in Tables 1 and 2. In this analysis, 84 participants were included in the 31 studies. Of the 84 participants, 84.5% had an ASD diagnosis only whereas 15.5% had a secondary diagnosis in addition to ASD. Race and severity of ASD symptoms were not reported for the majority of participants (67.8% and 71.4%, respectively). A total of 72.6% were male and 27.4% were female. Participants mostly fell in the early childhood (40.4%) or middle childhood (52.3%) categories. Participants primarily communicated using prelinguistic means of communication (e.g., leading an adult, pointing; 35.7%) or used one-word communication (using an SGD or vocally; 47.6%). More participants were new to using the SGD (63%) compared to participants who had some experience using an SGD (37%). In terms of settings, the intervention was mainly implemented in school environments (69%) or a clinic (27%). The intervention was primarily implemented by a researcher (71%). In terms of the primary verbal operant targeted, manding was taught for the majority of participants (84.5%). Vocalizations were only measured and secondarily targeted for 12% of participants. All participants received reinforcement (specific reinforcement for manding, and generalized reinforcement for tacting and intraverbal) as part of the behavioral intervention. In addition, for most participants, the intervention also included prompts (95%) and prompt delay (90%). Behavior chain interruption strategy was used for teaching 19% of participants to mand for missing items. Backward chaining was used to increase the complexity of a verbal response for 9.5% of participants. A total of 70% of participants received the intervention in a DTT context whereas 30% of participants received the intervention in a naturalistic context. Most participants (79.7%) used Proloqu2Go as the communication app on their devices. Finally, social validity, generalization, and maintenance were collected for only some participants (20%, 44%, 12%, respectively).

CEC Standards

Overall, all studies met most or all quality indicators under the following six categories: setting, description of practice, implementation fidelity, internal validity, dependent variable, and visual analysis. However, 17 studies did not report how a diagnosis was determined, 11 studies did not report background information about the intervention agent, and 21 studies did not report information about the nature of training (or amount of training) received by the intervention agent (see the supplemental table).

Tau-U and Moderator Analyses

Overall, intervention effect estimates across communication measures reflected moderate to very large changes in participant outcomes according to the interpretation guidelines described by Vannest et al. (2016). Table 3 provides a summary of Tau-U results. Specifically, mand outcomes (Tau-U = 0.92, $p < 001$, 95% CI [0.85, 0.98], $SD = 0.13$, range 0.39–1.00) and intraverbal outcomes (Tau-U = 0.81, $p < 001$, 95% CI [0.71, 0.90], $SD = 0.35$, range – 0.13 to 1.0) reflected overall large to very large changes, whereas tact outcomes (Tau-U = 0.60, $p < 001$, 95% CI [0.49, 0.72], $SD = 0.29$, range 0.07–1.00) and vocalizations outcomes (Tau-U = 0.77, $p < 001$, 95% CI = [0.63, 0.94], $SD = 0.28$, range 0.15–1.00) reflected overall moderate changes. Results of the moderate analyses indicated that none of eligible variables moderated intervention effectiveness in relation to mand outcomes.

Discussion

In this review, we summarized and meta-analyzed data for 84 participants with ASD across 31 studies that included tablet-based SGDs to increase the communication of individuals with ASD. Overall, our findings are consistent with previous reviews that found SGDs to be effective at increasing the communication of individuals with ASD (e.g., Morin et al., 2018; Muharib & Alzrayer, 2018; Tincani et al., 2020).

Specifically, findings from the current meta-analysis reveal a pattern of outcomes that highlights the nuanced effectiveness of tablet-based SGDs. One key finding is that interventions involving tablet-based SGDs resulted in large to very large changes in mand and intraverbal responses and moderate changes in tact responses and vocalizations.

Table 1 Summaries of the Included Studies

Study	Participants (sex, race/ethnicity, age and diagnosis)	Settings	Interventionist	Experimental design	Preference assessments	Type of device and application	Dependent Variables	Independent variables; context	Generalization and maintenance
Alzrayer et al. (2017)	2 male children (8–9 years old), ASD and speech impairment	School	Researcher	Multiple probe across participants	Interviews and free operant	iPad, Proloqu2Go	Manding for preferred items	LTM prompts (verbal, gestures, and physical) 10 s prompt delay, and differential reinforcement; DTT	G across toys and activities; G successful for both participants
Alzrayer et al. (2019)	3 male (2 Black, 1 Latino) children (7–10 years old), ASD, ID, and speech impairment	School and clinic (one child)	Researcher	MBL across behaviors	Interview and MSWO	iPad, Proloqu2Go	Manding for items, intraverbals (answering personal questions), and vocalizations for 1 child	LTM prompting (verbal, gestural, and full physical), 3 s prompt delay, and differential reinforcement; DTT	G across items for all children and personal questions for one child. Successful M 2 weeks post intervention for one child; manding G successful for all children, intraverbal G successful for one question
Alzrayer (2020)	3 male and 1 female children (3–5 years old), ASD	Clinic	Therapist	MBL across participants	Interviews and free operant	iPad, PECS IV. app	Manding for preferred items using modified PECS Phase IV protocol and vocalizations	Physical prompts, backward chaining, differential reinforcement, and 5 s time delay for vocalizations only; naturalistic	G across settings (kitchen and edible); G successful for all participants with iPad
Alzrayer et al. (2020)	1 female (White) child (6 years old), ASD, developmental disability, and sensory integration disorder	School	Researcher	Multiple probe across participants	Interview and MSWO	iPad, GoTalk Now	Manding for preferred items and vocalizations	LTM prompts (verbal, gestural, physical), 1-5 s progressive time delay, and differential reinforcement; DTT	G across a teacher and M 2 weeks post intervention; M and G successful for all participants

Table 1 (continued)

Study	Participants (sex, race/ethnicity, age and diagnosis)	Settings	Interventionist	Experimental design	Preference assessments	Type of device and application	Dependent Variables	Independent variables; context	Generalization and maintenance
Carnett et al. (2018)	1 male child (5 years old), ASD	Clinic	Researcher	MBL across responses	Parent interview	iPad mini, Proloqu2Go	Intraverbal fill-ins (songs)	BCIS, 5 s time delay, LTM prompting (verbal and gestural), differential reinforcement (enthusiastic vs. neutral praise for independent vs. prompted responses); DTT	None
Carnett et al. (2019)	2 male and 1 female children (5–13 years old), ASD, and ASD with Down Syndrome (one child)	School and clinic (one child)	Researcher	Multiple probe across participants	RAISD Interview and paired choice	iPad mini, Proloqu2Go	Manding for actions	BCIS, reinforcement (social praise and tangible), LTM prompts (gestural, vocal, partial physical, and full physical), 5 s prompt delay; DTT	G across items and M 1–2 months post intervention; G successful for 1 participant and M successful for all participants
Carnett et al. (2020)	2 male and 1 female children (5–13 years old)—ASD, and ASD with Down Syndrome (one child)	School and clinic (one child)	Researcher	MBL across participants	Interview and Paired choice	iPad mini, Proloqu2Go	Manding for information (where is ….?)	BCIS, reinforcement (social praise and tangible), LTM prompts (gestural, vocal, partial physical, and full physical), 5 s prompt delay; DTT	G across novel missing items for all children and across communicative partners for two children, M 1 month post intervention for 2 children; G successful for 1 participant and M successful for 2

Table 1 (continued)

Study	Participants (sex, race/ethnicity, age and diagnosis)	Settings	Interventionist	Experimental design	Preference assessments	Type of device and application	Dependent Variables	Independent variables; context	Generalization and maintenance
Carnett et al. (2021)	1 female (White) adult (20 years old), ASD and speech impairment	School	Teacher	Reversal design	Brief MSWO	iPad, GoTalk Now	Manding for preferred items	Most to least prompts, differential reinforcement; naturalistic	None
Genc-Tosun et al. (2022)	2 male children (5 years old), ASD	Home and clinic	Teacher and researcher	Multiple probe across responses	Interviews, single-stimulus, and multiple stimulus with replacement	iPad, Dokun Konus	Manding for preferred items, tact (what is this?), and intraverbals (answering personal questions)	Most to least prompts (full physical, partial physical, and gestural), 1 s and 5 s prompt delay, and reinforcement; DTT	G across settings and adults, M 1–5 weeks post intervention; G and M successful for both participants
Gevarter et al. (2021)	3 male (2 Latino, 1 Native-American) children (3–4 years old), ASD, and ASD with hearing impairment (one child)	Home	Parent	Multiple probe across participants	Parent report	iPad, GoTalkNow	Mand (item requests) and other communicative responses (rejecting, requesting assistance, or commenting/responding)	Environmental arrangements, 5 s prompt delay, verbal prompts, SGD proximity, reinforcement; naturalistic	G for requesting and tacting; G successful for requesting and mixed for tacting
Holyfield (2021)	4 male children (9–11 years old), ASD	School	Researcher	MBL across participants with an embedded alternating design	None	iPad, Proloqu2Go and LAMP	Intraverbal (within a context of reading)	Modeling, visual prompt, 3 s prompt delay, and reinforcement; DTT	G across a novel app (LAMP), M began 2 weeks post intervention; mixed G and M results
King et al. (2014)	2 female and 1 male children (3–5 years old), ASD	School	Researcher	Multiple probe across participants	Interviews and paired choice	iPad, Proloqu2Go	Manding for preferred items using modified PECS Phases 1–4 protocol, and vocalizations	Most to least prompts (full physical, partial physical, and gestural), backward chaining, and reinforcement: DTT	None

Table 1 (continued)

Study	Participants (sex, race/ethnicity, age and diagnosis)	Settings	Interventionist	Experimental design	Preference assessments	Type of device and application	Dependent Variables	Independent variables; context	Generalization and maintenance
Krcek (2015)	4 male and 1 female children (3–4 years old), ASD	Clinic	Therapist	MBL across responses	Paired choice	iPad, Proloqu2Go	Mand, tact, and Intraverbal	Prompts (gestural, verbal, model, and physical prompts), 3 s prompt delay, and reinforcement; DTT	None
Lorah et al. (2013)	5 male children (3–5 years old), ASD	School	Researcher	Reversal design	MSWO	iPad, GoTalk Now	Manding for preferred items	Physical prompts, 5 s prompt delay, differential reinforcement, and echoic prompts for vocalizations; DTT	M embedded in intervention for 4 participants; M successful for all participants
Lorah et al., (2014a)	4 male children (4–6 years old), ASD	School	Researcher	Multiple probe across participants	MSWO	iPad, Proloqu2Go	Manding for preferred items	Differential reinforcement; DTT	M 5–7 weeks post intervention; M successful for all participants
Lorah et al., (2014b)	1 male and 1 female children (5 and 6 years old), ASD	Clinic	Researcher	MBL across participants	None	iPad, Proloqu2Go	Tact (I see…, I have…)	5 s time delay, full physical prompt, and reinforcement (vocal social praise); DTT	None
Lorah et al. (2015)	1 female and 1 male children (8 and 12 years old), ASD	Clinic	Researcher	MBL across responses	None	iPad, Proloqu2Go	Intraverbal (answering personal questions	5 s prompt delay, full physical prompt, and reinforcement (vocal social praise); DTT	M immediately following intervention; M successful for both participants

Table 1 (continued)

Study	Participants (sex, race/ethnicity, age and diagnosis)	Settings	Interventionist	Experimental design	Preference assessments	Type of device and application	Dependent Variables	Independent variables; context	Generalization and maintenance
Lorah and Parnell (2017)	2 female and 1 male children (3–4 years old), ASD	School	Teacher and graduate students	MBL across participants	None	iPad mini, Proloqu2Go	Tacting (visual stimuli within a book)	5 s prompt delay, full physical prompt, & reinforcement (vocal social praise); DTT	M for 2 participants; M successful for both
Lorah (2018)	2 female and 1 male children (3–4 years old), ASD	School	Researcher	MBL across participants with an embedded changing criterion design	MSWO	iPad mini, Proloqu2Go	Manding for preferred items	Physical prompt, 5 s prompt delay, and reinforcement; naturalistic	Minimum of 2 M probes post intervention; M successful for all participants
Lorah et al. (2019)	2 female and 1 male children (3–4 years old), ASD	School	Teacher	MBL across participants	None	iPad mini, Proloqu2Go	Manding to peers for a missing puzzle piece	BCIS, physical prompt, 5 s prompt delay, and reinforcement; naturalistic	M immediately following intervention; M successful for all participants
Lorah et al. (2021)	2 male, 1 female (White, Latino, Asian) children (3–4 years old), ASD	School	Teacher	MBL across participants	None	iPad mini, Proloqu2Go	Manding to peers for missing art materials	BCIS, physical prompt, 3 s prompt delay, and reinforcement; naturalistic	M immediately following intervention; M successful for 2 of 3 participants
Lorah and Griffen (2023a)	2 female and 1 male (2 White, 1 Asian) children (2–5 years old), ASD	School	Researcher	MBL across participants	MSWO	iPad mini, Proloqu2Go	Manding for preferred items and traveling to communicative partners	Graduated guidance, 5 s prompt delay, differential reinforcement, and echoic prompts for vocalizations; DTT	None

Table 1 (continued)

Study	Participants (sex, race/ethnicity, age and diagnosis)	Settings	Interventionist	Experimental design	Preference assessments	Type of device and application	Dependent Variables	Independent variables; context	Generalization and maintenance
Lorah and Griffen (2023b)	2 female and 1 male children (2–5 years old), ASD	School	Researcher	MBL across participants	MSWO	iPad mini; Proloqu2Go	Manding for a missing puzzle piece	BCIS, physical prompt,5 s prompt delay, reinforcement; naturalistic	M immediately following intervention; M successful for all participants
McLay et al. (2015)	3 male and 1 female (3 Pacific, 1 Asian) children (5–10 years old), ASD	School	Researcher, teachers, and SLPs	MBL across participants with an embedded alternating treatment design	Free operant	iPad mini; Proloqu2Go	Manding for preferred items	Graduated guidance, 10 s prompt delay, reinforcement; DTT	M 5–8 weeks post intervention; 3 of 4 children maintained SGD-based manding
Muharib et al. (2019)	1 male (White) child (8 years old), ASD	School	Researcher	Multiple probe across participants	Interviews and MSWO	iPad, Proloqu2Go	Manding for preferred items and vocalizations	LTM prompts (verbal, gestural, and physical), 5 s prompt delay, and differential reinforcement; DTT	G across teachers, M 2 weeks post intervention; G and M successful for all participants
Rinaldi (2019)	1 male (White) child (4–5 years), ASD	School	Researcher	Multiple probe across responses	Non-structured observations	iPad, GoTalk Now	Manding for actions	Physical prompt, 5 s prompt delay, reinforcement; naturalistic	G across adults for 1 participant; G successful
Sawchak et al. (2023)	4 male and 1 female (3 Mixed, 2 White) children (7–10 years old), ASD	School	Researcher	Delayed multiple probe across participants	Interviews and paired choice	iPad, Proloqu2Go	Manding for items in a sequence (hello, request, thank you); part intraverbal	Physical prompt, 10 s prompt delay, and reinforcement; DTT	G across adults, M began 3–8 weeks post intervention; M and G for all participants
Tullis et al. (2019)	1 male child (6 years old), ASD and dyspraxia	Clinic	Therapist	Multiple probe across stimulus sets	None	iPad, TouchChat	Intraverbal (why is this a problem?)	Textual and vocal prompt, 0 s prompt delay, and reinforcement; DTT	M began 1–2 days post intervention: M successful across stimulus sets

Table 1 (continued)

Study	Participants (sex, race/ethnicity, age and diagnosis)	Settings	Interventionist	Experimental design	Preference assessments	Type of device and application	Dependent Variables	Independent variables; context	Generalization and maintenance
Waddington et al. (2017)	1 male child (8 years old), ASD	Clinic, school, and home	Researcher, teacher, and parent	Multiple probe across settings	MSWO	iPad, Proloqu2Go	Manding for preferred items and traveling to communicative partners	Graduated guidance, 10 s prompt delay, and reinforcement, DTT	G across settings (different sections within clinic, school, home); G successful
Wendt et al. (2019)	2 male adolescents (14–16 years old), ASD with OCD and ASD with ID; 1 male adult (23 years old), ASD	Clinic	Researcher	MBL across participants	Single stimulus	iPad, SPEAKall!	Manding for preferred items using PECS protocol phases 1 to 5	Most to least prompts and differential reinforcement; DTT	G across toys, M began 4–6 weeks post intervention; G and M successful for all participants
Yong et al. (2021)	1 male (Asian) child (6 years old), ASD	School	Researcher	MBL across participants	Interviews and paired choice	iPad, Proloqu2Go	Manding for preferred items	LTM prompts (verbal, gestural, and physical), 5 s prompt delay, and differential reinforcement; DTT	None

We only included information of participants eligible for this meta-analysis

ASD autism spectrum disorder, *BCIS* behavior chain interruption sequence, *DD* developmental disability, *DTT* discrete trial training, *G* generalization, *ID* intellectual disability, *LTM* least to most, *MBL* multiple baseline, *MSWO* multiple stimulus without replacement, *M* maintenance, *OCD* obsessive compulsive disorder, *RAISD* reinforcer assessment for individuals with severe disability, *SGD* speech generating devices, *SLP* speech language pathologist

Table 2 Main characteristics of the 84 participants

Category	Subcategory	% of participants
Age group	Early Childhood	40.4%
	Middle Childhood	52.3%
	Adolescence	4.7%
	Adulthood	2.3%
Race/ethnicity	Not reported	67.8%
	White	11.9%
	Latino	4.7%
	Asian	4.7%
	Mixed	3.5%
	Pacific Islander	3.5%
	Black	2.3%
	Native American	1.1%
Diagnosis	ASD only	84.5%
	ASD +	15.5%
Severity of ASD symptoms	Not reported	71.4%
	Severe	20.2%
	Moderate	8.3%
Sex	Male	72.6%
	Female	27.4%
Communication Level	Prelinguistic	35.7%
	One-word	47.6%
	Sentences	4.7%
	Not reported	11.9%
Prior Experience with SGD	New	63%
	Prior user	37%
Setting	School	69%
	Clinic	27%
	Home	6%
Interventionist	Researcher	71%
	Practitioner	31%
	Parent	4.7%
Primary Verbal Operant	Mand	84.5%
	Tact	14.2%
	Intraverbal	19%
Vocalizations	Targeted	12%
Behavioral Intervention Components	Reinforcement	100%
	Prompts	95%
	Prompts delay	90%
	BCIS	19%
	Backward chaining	9.5%
Context	DTT	70%
	Naturalistic	30%
Communication App	Proloqu2Go	79.7%
	GoTalk Now	8.3%
	LAMP	4.7%
	PECS IV	4.7%
	SPEAKall!	3.5%
	Dokun Konus	2.3%
	Touch Chat	1.1%

ASD autism spectrum disorder, *BCIS* behavior chain interruption strategy, *SGD* speech-generating device

Percentages in setting and interventionist categories do not add up to 100 because a few participants received an intervention across settings or interventionists. Percentages do not add up to 100 in the primary verbal operant because data were collected across several verbal operants for some participants

Table 3 Tau-U Across Variables and Communication Measures

Variable	Mand			Tact			Intraverbal			Vocalizations		
	n	*M* Tau-U	*SD*	*n*	*M* Tau-U	*SD*	*n*	*M* Tau-U	*SD*	*n*	*M* Tau-U	*SD*
Age												
Early childhood	31	.91	.14	8	.56	.27	5	.54	.56	5	.68	.36
Middle childhood	34	.92	.13	4	.92	.11	11	.93	.09	5	.83	.18
Adolescence	4	.99	.01									
Adult	3	1.00	.00									
Diagnosis												
ASD	59	.92	.14	11	0.67	.30	14	.79	.37	8	.73	.31
ASD +	12	.97	.05				2	1.00	.00	2	.85	.09
Communication levels												
Prelinguistic	24	.93	.14	3	.91	.13	8	.92	.11	3	.61	.41
One word	34	.89	.14	9	.59	.29	7	.67	.49	3	.67	.29
Full sentences	3	.98	.03				1	1				
Prior experience with SGD												
Current user	25	.89	.15	3	.60	.13	3	.98	.03			
New user	46	.96	.12	9	.70	.33	13	.54	.38	10	.75	.28
Setting												
Clinic	17	.94	.11	8	.69	.35	10	.76	.43	4	.93	.04
School	51	.92	.14	3	.60	.13	5	.88	.12	6	.64	.32
Home	5	.78	.12	1	.76		1	1				
Interventionist												
Researcher	51	.93	.11	3	.97	.05	9	.92	.10	6	.64	.32
Practitioner	22	.90	.16	9	.58	.26	7	.67	.50	4	.93	.04
Parent	4	.98	.04									
Context												
DTT format	49	.92	.13	9	.77	.23				6	.64	.32
Embedded	22	.93	.14	3	.60	.13				4	.91	.03

Blank cells indicate instances of variables not present in the data set. For variables with one case ($n = 1$), Tau-U represents outcome for that specific case

A noteworthy observation from our review pertains to the prominence of mands as the most targeted verbal operant among participants with ASD ($n = 71$), which is consistent with previous reviews (e.g., Muharib & Alzrayer, 2018; Tincani et al., 2020). One reason for the pronounced outcomes for mands is that mands are the only verbal operant that results in attainment of a specific reinforcer (e.g., a child asks for candy, the child receives candy). Thus, a child may be more motivated to engage in a mand to acquire a specific reinforcer than to tact an object or a picture. Intriguingly, our study found interventions involving tablet-based SGDs resulted in greater change in intraverbal responses compared to tact responses, despite participants often lacking prior experience with SGDs for either operant; notably, although both tacts and intraverbals yield social or arbitrary reinforcement (e.g., praise) and intraverbals represent a higher-level verbal operant, the outcomes for intraverbals were more pronounced.

In addition, we conducted analyses to determine whether certain variables moderated the estimated effectiveness of interventions involving tablet-based SGDs. Our results show that there are no statistically significant differences in any of these variables for mand outcomes, which suggests that tablet-based SGDs can be effective in promoting mand responses for individuals with ASD regardless of these participant and study characteristics. Furthermore, our descriptive analysis sheds light on the uneven distribution of studies across various demographic and methodological dimensions. Notably, the majority of participants were male, diagnosed solely with ASD, and situated within the childhood age range. In contrast, a mere 27.4% represented females, while only 15.5% exhibited an additional diagnosis alongside ASD, and 7% were beyond the childhood phase. Similarly, our findings highlight a prevalent trend wherein interventions were predominantly implemented by researchers, constituting 71% of the cases, and often following a

DTT format (70%). This underscores the need for more studies conducted by practitioners and parents and within the natural routine of the individuals with ASD (Ganz et al., 2019).

Finally, we assessed the extent to which the included studies adhered to the CEC (2014) quality indicators. Notably, although the majority of indicators were met, a recurrent shortfall pertained to the lack of detailing pertaining to training procedures and required training duration for successful intervention implementation. This trend potentially arises from the substantial involvement of researchers as intervention implementers for most participants (71.4%).

Limitations and Directions for Future Research

There are a few limitations that should be considered when interpreting findings from this review. First, as noted previously, we were unable to conduct moderator analyses for tact, interverbal, and vocalization outcomes due to an insufficient number of cases across all categories. Likewise, moderator analyses were not possible for specific categories under mand outcomes (e.g., adolescent and adult variables, home setting variable). To inform best practices in supporting the communication needs of individuals with ASD through tablet-based SGDs, it will be important to examine for whom and under which conditions these communication supports are effective. The limited number of cases representing certain communication measures and participant and study characteristics underscores the urgent need for additional research to build the literature base, thus permitting future examination of potential moderators. Second and related to the first limitation, although our findings suggest that interventions involving tablet-based SGDs produce moderate to very large changes in outcomes for individuals with ASD, is it possible that participant and study characteristics beyond those reported in this review may have moderated intervention outcomes. For example, due to insufficient information in the included studies, we did not code for participants' motor abilities, unique features or settings used to navigate apps, or interventionists' prior experience and training. These additional characteristics should be considered in future systematic literature reviews.

Our findings also revealed significant gaps in the literature base that should be addressed in future research. Of particular note were the limited number of cases involving individuals falling under the adolescent and adult categories, practitioner- and parent-implemented interventions, and implementation in natural contexts. We also found that a majority of cases focused on mand outcomes and few studies included measures of social validity, generalization and maintenance. To advance research and practice to support the communication needs of individuals with ASD, researchers will need to explore how tablet-based SGDs can be used in natural environments (e.g., inclusive school settings, community settings, home) by natural implementers (e.g., peers, teachers, family members) across all age groups as well as effective strategies for promoting skill generalization and maintenance with intentional assessment of social validity from the perspective of those supporting individuals with ASD and those who receive such support (Horner et al., 2005; Reichow et al., 2011).

In addition, our findings show a lack of race and ethnicity reporting in research related to tablet-based SGDs. Without data on the racial and ethnic backgrounds of participants in SGD studies, it becomes challenging to ensure that the benefits and outcomes of SGD interventions are universally applicable. Cultural sensitivity is vital in providing effective communication support for individuals with diverse backgrounds, including those from different racial and ethnic groups (Battaglia, 2017). For example, a parent of a child with ASD may prefer her child to communicate using their home language over English or in both languages using an SGD. Researchers should report and incorporate participants' racial and ethnic backgrounds in SGD interventions to meet the specific needs and cultural contexts of individuals with ASD.

Implications for Practice

Our findings suggest that interventions involving tablet-based SGDs are effective in enhancing the communication skills of individuals with ASD. Therefore, we encourage practitioners and caregivers to consider the use of these devices, particularly given the evidence presented in this review and the potential advantages, such as cost-effectiveness, portability, and social acceptability (Lorah, Holyfield, Griffen, et al., 2022). However, as with any decision related to planned support, it is imperative to conduct a thorough assessment, including the social validity from the perspective of the AAC user, to determine whether a tablet-based SGD option is suitable. Assessments might include considerations related to motor skills (e.g., ability to point, grasp, type, swipe), discrimination skills (e.g., ability to identify real objects and pictures), hearing and vision needs, and the durability of the device. It is also important to consider the individual's communication preference and availability of adult training and support (Alzrayer & Banda, 2017; Beukelman & Light, 2019). Ultimately, the specific communication needs and abilities of the individual should serve as the guiding principles in the decision-making process. By thoroughly assessing these factors, practitioners and caregivers can make informed choices regarding the suitability of a tablet-based SGD as a communication support option.

Although there were limited cases across certain variables, evidence from this review suggests that SGDs can be effective across different settings, implementers, and

contexts. It is essential to stress the importance of fostering communication in natural contexts, as this may facilitate skill generalization (Ganz et al., 2019). To ensure that individuals with ASD have ample opportunities to use SGDs across various settings and people, it is imperative to establish collaborative teaming among teachers, related services providers (e.g., speech-language pathologists, occupational therapists), and caregivers. Collaborative teaming plays a vital role in embedding communication opportunities within the natural routines and activities of individuals with ASD throughout the day. Moreover, it may assist in determining the most effective approaches for providing training to the adults involved in the individual's life. For example, teams can collaboratively decide whether and how training will occur (e.g., live coaching, telehealth support) and by whom to ensure those involved in supporting the communication and language development for individuals with ASD have the resources and knowledge necessary to do so. Adult training may include aspects such as how to program the SGD app to include a certain number of icons (based on the individual's preferences and their ability to discriminate between icons), how to select specific communication goals, and how to use prompts and prompt fading strategies (e.g., least to most, most to least). Although the studies lacked information on the racial and ethnic backgrounds of participants, it is essential to tailor SGD interventions to the specific needs of individuals with ASD, ensuring that the interventions align with the cultural values and contexts of these individuals (Battaglia, 2017).

In conclusion, findings from this study suggest the efficacy of tablet-based SGDs in advancing the communication skills of individuals with ASD and highlights their estimated effects across distinct verbal operants and vocalizations. Furthermore, our findings underscore the need for more studies in certain underexplored areas.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10803-023-06173-6.

Declarations

Conflict of Interest The authors declare no conflict of interest.

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