A delayed intervention start randomized controlled trial of high- and low-tech communication training approaches for school-age children with autism spectrum disorder and comorbid intellectual disability

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Number of text pages:	20
Number of tables:	1
Number of figures:	3

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Funding: The charity RESPECT and the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme (FP7/2007-2013). Grant Number: PCOFUND-GA-2013-608728

Abstract

A delayed intervention start randomized controlled trial was designed to compare outcomes of communication training interventions. The outcomes in this trial consisted of verbal operants (i.e., mands, tacts, intraverbals). The primary hypothesis testing for the study included a comparison of outcomes resulting from function-based applied behavior analytic (ABA) versus eclectic non-ABA forms of classroom-based communication training (waitlist control), as well as a comparison of outcomes resulting from high- versus low-tech forms of function-based augmentative and alternative communication training. The community-based sample consisted of 29 autistic children diagnosed with comorbid Intellectual Disability (ID). Participants were randomized to a form of function-based communication training and received approximately 3 months of communication intervention. Multilevel modeling of learner outcomes indicated that the function-based approach to communication training yielded far greater improvements than the eclectic classroom-based alternative, but significant differences were not observed between outcomes of high-tech and low-tech forms of function-based communication. Results from this trial are consistent with earlier investigations and provide supporting evidence that both high- and low-tech forms of function-based intervention are effective for use with individuals with ASD, with or without accompanying ID. Additional discussion is provided regarding further research into how technology is applied and incorporated into behavior analytic programming.

Keywords: function-based AAC, speech-generating devices, autism, intellectual disability

Introduction

Autistic children and adults present with characteristic difficulties in the areas of socialization and communication (American Psychiatric Association, 2013). Historical estimates related to the linguistic abilities of this population have varied, though longitudinal modeling studies have suggested that at least 30% of these individuals will, without early and intensive behavioral intervention, present with limited or absent vocal-verbal repertoires (Tager-Flusberg & Kasari, 2013). For those individuals who do not acquire a communicative repertoire from naturally-occurring contingencies, Augmentative and Alternative Communication (AAC) systems are often introduced to enhance those existing communicative repertoires (Ganz, 2015; Gilroy et al., 2017; Sigafoos et al., 2016).

Broadly, the term AAC refers to a class of methods and tools that are designed to improve the quality and quantity of social interactions (Ganz, 2014; Schlosser & Wendt, 2008; Sigafoos et al., 2016). Within this class of methods, there are forms of aided (e.g., technology, materials) and un-aided AAC (e.g., American Sign Language; Mirenda & Iacono, 2009). For autistic individuals, there is evidence that both aided (e.g., Gilroy et al., 2017; Lorah et al., 2015) and un-aided (e.g., Ganz & Gilliland, 2014; Tincani, 2004) forms of AAC can be used to establish functional social behavior. However, it warrants noting that most of the literature on AAC with ASD has focused on the initial acquisition of a mand repertoire (Gilroy et al., 2017; Lorah et al., 2021; Tincani et al., 2020).

Although un-aided forms of AAC can be used with autistic individuals, this study focuses on various implementations of aided AAC. Within aided forms of AAC, there exists a continuum of modalities that range from “low-tech” (LT) to “high-tech” (HT) forms of assistive technology (see McNaughton & Light, 2013, for a discussion). At the lower extreme, approaches such as the

Picture Exchange Communication System (PECS) use an exchange of laminated picture cards to establish functional communication and facilitate social interactions (Frost & Bondy, 2002). Although not a direct translation of Skinner's Verbal Behavior (Skinner, 1957), this structured teaching approach targets several of the verbal operants identified in the verbal behavior taxonomy (see Tincani et al., 2020, for a relevant discussion). Support for the use of PECS is considerable for both children (Bondy, 2012; Flippin et al., 2010) and adults who present with limited social-communicative repertoires (Preston & Carter, 2009; Stoner et al., 2006). Furthermore, positive responses have been demonstrated for early communicators across different cultures as well (e.g., Travis & Geiger, 2010; Yokoyama et al., 2006). In contrast to LT modalities, the upper extreme of this range leverages modern computer hardware (i.e., tablets, phones) and the novel functionality that they support (e.g., speech output, keyboard entry).

The speech-generating functionality provided in modern hardware has provided an alternative to traditional AAC modalities, whereby the communication response previously took the form of either a manual sign, an exchange of picture cards, or some other functional equivalent. Since their introduction, Speech-Generating Devices (SGDs) and related forms of AAC have been rapidly adopted in clinical practice and are increasingly represented in the applied literature (see Gilroy et al., 2017; Lorah et al., 2015, for reviews). At present, the efficacy of HT AAC is supported by a combination of both single-case (e.g., Achmadi et al., 2012; Lorah et al., 2013; van der Meer et al., 2012) and group-design research (e.g., Gilroy et al., 2018).

Meta-analytic syntheses of AAC intervention studies have indicated that aided forms of AAC interventions are efficacious for establishing communicative repertoires for autistic individuals (e.g., Ganz, Davis, et al., 2012; Ganz, Earles-Vollrath, et al., 2012). Although this approach has been found efficacious, there are a variety of options available for aided AAC at this time, and research directly comparing outcomes from HT and LT AAC remains limited. For instance, Lorah et al. (2013) conducted single-case evaluations of high- and low-tech AAC in an alternating treatments design and observed comparable levels of responding after training, but varying degrees of preference, when learners were exposed to each form of AAC.[1] Additionally, a pilot study by Gilroy et al. (2018) evaluated outcomes from HT and LT AAC using randomized assignment to AAC modality and did not find significant differences between modalities. Although these works both support the utility of high-tech AAC approaches, the literature remains limited regarding the potential for differential benefits of high- and low-tech forms of AAC.

Research Questions

Over two decades prior, Mirenda (2001) presented a prescient appraisal of HT AAC and questions that would need to be answered. Mirenda (2001) noted that there was less of a need to determine whether HT AAC methods work and more of a need to determine whether these approaches work *better than* less complicated alternatives (i.e., LT AAC). Absent continued research and consensus in this area, there are few empirical studies and guides that provide an answer to this question. For example, some advocate for selecting an AAC approach based on individual preference and determination (i.e., more social validity; e.g., Lorah, 2016; Lorah et al., 2013) whereas others suggest exploring HT AAC (i.e., speech-generating devices; SGDs) only after first establishing a communicative repertoire using LT AAC (i.e., more closely aligned with historical data; e.g., Bondy, 2019).

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[1] We note that this study compared training using picture exchange and SGD conditions and this may or may not be generalizable to comparisons between SGD and PECS, specifically.

The purpose of the present study was to experimentally examine the differential benefits of various forms of aided AAC intervention for autistic learners with a comorbid intellectual disability. Specifically, a follow-up to the earlier Gilroy et al. (2018) group design trial was designed to extend the literature on AAC for autistic learners in two ways. First, the earlier trial focused on autistic students who did not present with co-morbid intellectual disabilities, and intervention was delivered in public school settings. The subgroup of learners targeted in this study, presenting with autism and comorbid intellectual disability, has been estimated at levels ranging from 50-70% of the autistic population (see Matson & Shoemaker, 2009, for a review). As such, the current trial was designed to explore whether the nonsignificant differences observed in the Gilroy et al. (2018) trial would also be found in this subset of the autistic population—a subset that traditionally requires greater support (i.e., served in a specialized school setting). Second, the methodology in this trial extended earlier work by facilitating population-level comparisons of relevant teaching approaches (i.e., eclectic classroom strategies, function-based training) as well as AAC modalities (i.e., LT, HT). In this way, inferences can be drawn regarding the effects of a function-based approach overall as well as whether any particular implementation of that approach was associated with greater improvements. The specific research questions (RQs) are:

> **<u>RQ1:</u>** To what degree do outcomes from function-based AAC intervention based on verbal operants (i.e., instances of communication demonstrated on an assessment of functional communication) differ from eclectic, non-ABA, classroom-based communication interventions?

RQ2: To what degree does the modality (high-tech, low-tech) of function-based AAC correspond with the acquisition of the verbal operants (i.e., mands, tacts, and intraverbals) on an assessment of functional communication?

Methods

Design

A delayed intervention start randomized controlled trial (RCT) was used to draw comparisons between a delayed intervention start control group (i.e., eclectic classroom communication strategies) and an experimental intervention group (AAC; i.e., function-based communication training). The RCT methodology is one means of comparing the outcomes of one or more competing forms of intervention (e.g., HT vs LT AAC; Smith, 2013) and, in recent years, various behavior analysts have called for the use of such methods when they better suit specific research questions (see Hanley, 2017, for a discussion). The delayed intervention start RCT design used in this trial can be likened to a multiple-baseline design, whereby the lagged introduction of an independent variable allows for an inspection of differences between a control group and an experimental group (i.e., eclectic classroom-based strategies vs. function-based AAC). Across each of the classrooms that agreed to participate in the trial, prospective study participants were randomized to the type of AAC at the individual classroom level (i.e., ~50% high-tech [HT], ~50% low-tech [LT]). Consistent with Gilroy et al. (2018), this manner of randomization deviated from true randomization to better balance the composition of learner age and general skill level between groups at various points throughout the trial. Although a deviation from more robust matching approaches (e.g., based on IQ, symptom severity), this approach was both more pragmatic in community-based settings and was previously effective for constructing comparable groups in the prior trial. Randomization was performed using an online tool using de-identified participant numbers (Haahr, 1998) prior to measure communicative behavior in baseline.

The design and sequence of the trial are illustrated in Figure 1. The first leg of the trial consisted of classroom randomization to one of two conditions: eclectic classroom-based strategies (Waitlist Control; i.e., delayed intervention start condition) or function-based intervention (AAC). Following approximately three months of classroom-based intervention, the first leg concluded, and the second leg began as the original control group began function-based intervention (AAC). The second leg of the trial also consisted of approximately three months of classroom-based communication training intervention. Specifically, outcomes for both legs of the trial were assessed following approximately three months of intervention to control for variability in intervention dose.

Participant Characterization Measures

Prospective trial participants were administered a battery of measures to characterize both their social-communicative repertoires and their present levels of adaptive behavior at intake. Standardized measures were administered to ensure uniform measurement and comparable samples. The specific measures administered included:

Childhood Autism Rating Scale, Second Edition

The Childhood Autism Rating Scale, Second Edition (CARS-2) is a standardized instrument that is often used to assess the presence and severity of the symptoms of ASD (Schopler et al., 2010). This instrument has strong demonstrated internal consistency, with an estimated Cronbach's alpha of 0.93, and is often used as a component of comprehensive evaluations for ASD (Vaughan, 2011). This measure was completed by the study authors in conjunction with the Childhood Autism Rating Scale, Second Edition-Questionnaire for Parents or Caregivers (CARS2-QPC). The CARS2 was scored using information from parents, teachers, and direct observations by study authors. Those results were interpreted by the lead author, a licensed psychologist and behavior analyst, to confirm the presence of symptoms of autism.

Adaptive Behavior Assessment System, Third Edition

The Adaptive Behavior Assessment System-Third Edition (ABAS-3) is a standardized instrument routinely used to evaluate overall levels of adaptive behavior (Harrison & Oakland, 2015). Adaptive behavior broadly refers to the everyday skills necessary to function independently in daily life. The ABAS-3 has specific subscales related to socialization and communication and has been found to have good overall internal consistency, with an overall Cronbach's alphas ranging from 0.96 to 0.99 (Harrison & Oakland, 2015). This measure was completed by both parents and teachers of prospective study participants.

Criteria for Inclusion

Prospective participants were eligible for inclusion in the trial if they met several criteria. First, all prospective participants must have already received clinical diagnoses of both ASD and ID. Second, eligible participants needed to demonstrate symptoms consistent with ASD immediately before being included in the study. Symptoms of ASD were indexed using the CARS2-ST and this tool was used to confirm a continued presentation of ASD. Third, eligible trial participants needed to exhibit substantial deficits in both their social and communicative repertoires. These repertoire deficiencies were indexed using the respective subscales of the ABAS-3 (Socialization, Communication). Eligible participants demonstrated skills at least 1 standard deviation below their same-aged peers on both subscales. Fourth, the omnibus indicator of adaptive functioning of the ABAS-3 was used to confirm the continued presence of an Intellectual Disability (i.e., two standard deviations below average). Lastly, participants must have been free of any other current co-occurring conditions that might otherwise account for the differences observed in their social and communicative repertoires (e.g., seizure disorder, traumatic brain injury). Within an ideal design, participants would be naïve to all forms of communication training but the nature of service delivery in the country of Ireland rendered this factor impossible to control for in a community-based setting.

Participant Recruitment and Assignment

Recruitment took place in specialized educational settings located near the host University. Whereas primary schools often serve children with ASD in Ireland, specialized schools are traditionally reserved for children with ASD who present with comorbid disorders, such as ID. Given this arrangement, these specialized educational settings provided a convenient means of recruiting children with ASD and comorbid ID. Two specialized schools were contacted, one agreed to participate in the trial, and a total of eight classrooms and teachers agreed to participate in the trial.

Participant Sample

Study statistical power was estimated using data from the earlier Gilroy et al. (2018) trial. Specifically, the effects (e.g., Time, AAC Type), residual error, and variance-covariance matrix were extracted from the prior trial data to simulate study power using the *lmer* method in the *lme4* package (Bates et al., 2015) in the R Statistical Program (R Core Team, 2017). These quantities were extracted but then halved to approximate the greater challenges anticipated with the given population (i.e., lower starting level, lower rate of improvement). The effect size of interest, the Time x AAC Type interaction, was set to 2 (i.e., a difference of 2 or more instances of functional communication) given that +/- 1 instance of functional communication was not considered to be a clinically meaningful difference between approaches. The *simr* package

(Green & MacLeod, 2016) was used to perform simulations and determine the sample size necessary to detect the expected effect with sufficient statistical power. Simulations indicated that a total of 25 participants would be necessary to detect such an effect with 88% power (i.e., consistently above 80%; Range = 79.98 – 93.64). Information related to specific effect sizes, model variance, and simulation syntax is available in the Appendix as well as provided as supplemental materials.

A total of 33 school-aged children were nominated by school teachers and administrators. All participants had independent, previous evaluations by psychologists before they entered the specialized school setting. Within this sample, 1 child was ineligible to participate because they met the criteria for ASD and ID but also Down Syndrome. Additionally, 3 children who were eligible for inclusion in the trial were unable to complete the first leg of the trial due to unmanaged health issues (n = 1), irregular school attendance (n = 1), and issues associated with unsafe and challenging behavior before the trial (n = 1). Within the remaining sample, a total of 29 school-age children (M = 10.24 years; Mdn = 11, $Q1$ = 7, $Q3$ = 14) were eligible, participated in, and completed the trial. Participant characteristics overall, by group assignment and modality, are presented in Table 1. Videotaped experimental change measures at baseline revealed that overall levels of participant functional communication were low (i.e., functional communication responses/minute; M = 0.1, SD = 0.3, Mdn = 0, $Q1$ = 0, $Q3$ = 0). Furthermore, the limited number of vocal utterances recorded were primarily non-functional (i.e., unrelated to context).

Experimental Change Measures

Behavioral Communication Assessment

The primary outcome measures consisted of unassisted instances of functional communication. Specifically, the targets were drawn from the verbal behavior taxonomy of

Skinner's verbal behavior (i.e., mands, intraverbal-mands, tacts). It warrants noting that *functional* operants are not specific to modality (i.e., HT, LT AAC) but rather the context in which they occur (e.g., control of motivating operation [MO] vs. multiple controls; Sweeney-Kerwin et al., 2007). As such, a structured Behavioral Communication Assessment (BCA) task was designed to construct the stimulus conditions in which said functional communications should occur. Specifically, this procedure was designed to evoke mands, intraverbal-mands, and intraverbal-tacts in a structured approach that was agnostic to the form of communication (see Gilroy et al., 2018 for an example of this approach). A complete description of the procedures involved in the BCA is provided as supplemental materials.

The number of exposures to each set of stimulus conditions in the BCA (e.g., mands, intraverbal-mands) was held constant across learners to capture functional communication responses that occurred versus did not occur under respective stimulus conditions. This approach was suited to this type of investigation for several reasons. For instance, the assessment was linked to communication context, rather than form/topography, and captured a range of appropriate communication (e.g., picture card exchange, digital speech output, vocal language). As such, this approach provided significant flexibility in capturing functional communication without unnecessarily focusing on a specific topography. Additionally, the BCA is linked directly to the function-based approach emphasized in behavior analysis and targets a much wider range of operants than covered in most other studies (which have focused on individual operants, e.g., mands). This structured, live communication assessment was administered prior to and immediately following each leg of the trial.

Observer Agreement

Interobserver Agreement (IOA) was assessed for 83.5% of the experimental change measures (i.e., BCA). Each BCA was video recorded and later scored by trained observers using the BDataPro computer program (Bullock et al., 2017). Exact interval agreement was performed in the BDataPro program using the default settings (10s intervals). The overall agreement in the sample was 99.8% (*SD* = 1.36; Range = 83.33–100). Research assistants were masked to the identities of participants and their group assignments (i.e., teaching approach), and all measures were double entered to ensure accurate scoring and correct data entry.

General Procedures

Stimulus Preference Assessment

Study participants participated in a multi-step preference assessment to identify highly preferred items which may be used in the BCA and subsequent treatment (Fisher et al., 1996; Fisher et al., 1992). The initial battery of stimuli was selected from those endorsed on a parent- and teacher-completed form of the Reinforcer Assessment for Individuals with Severe Disabilities (RAISD; Fisher et al., 1996). These stimuli were subsequently included in a Paired Stimulus preference assessment (Pace et al., 1985) and the highest preferred stimulus was used in assessment and treatment so long as the item was selected in at least 80% of opportunities.

Communication Training

The primary interventions of interest were HT and LT forms of function-based AAC that targeted functional operants (Bondy & Frost, 2016). These interventions were delivered by trained graduate school students enrolled in a university-based applied behavior analysis training program. Graduate students were trained on all components of the intervention procedures before delivering therapy. Weekly supervision was provided by doctoral-level behavior analysts throughout the entirety of the trial. The supervising Behavior Analyst had received PECS Level 1 and PECS Level 2 workshop training and held the associated certificates from the creators of PECS, Pyramid Educational Consultants, Inc.

Treatment sessions with participating children took place in the context of the natural school day and classroom routines. These treatment sessions were approximately 15-20 minutes in duration, designed to fit within daily school routines and instruction, and were kept consistent to minimize the possibility of varying intervention dosages across classrooms and approaches. There were no parent-based services offered in conjunction with either of the assigned interventions. All intervention elements for learners took place in their school setting for approximately 3 months and concluded at the end of the programmed school year. Skill targets for both the HT and LT AAC interventions focused on the verbal operants listed in Phases I-VI of the PECS teaching protocol (Bondy & Frost, 2016; Gilroy et al., 2018).

Low-Tech (LT) AAC. All participants assigned to the LT group received function-based communication training using laminated picture cards. All picture cards, communication books, and sentence strips were constructed consistent with recommendations included in the PECS teaching protocol (Bondy & Frost, 2016). To maintain consistency across users and modalities, all cards were initially sized 3 x 3cm by default but were resized as necessary (e.g., to support discrimination training). The specific graphics used in the picture cards were derived from the free and open-source Mulberry Symbol Set (Paxton, 2015) wherever possible to control for varying image formats, but photographs of specific items were used as necessary.

High-Tech (HT) AAC. Participants assigned to the HT group received function-based communication using an SGD. The specific teaching strategies used with the SGD were based on existing extensions of the PECS teaching protocol using a touchscreen device (for an example, see King et al., 2014). All participants in the HT AAC group were provided with a 7” Samsung Galaxy™ tablet device that was preloaded and locked into a single application. That is, the function of the device was completely restricted to communication purposes. The use of a standardized model and platform across participants minimized the likelihood that device-level factors could complicate comparisons across groups. The application loaded onto each device was a cross-platform, open-source tool that had been successfully developed and utilized in an earlier RCT with children diagnosed with ASD (Gilroy, 2016; Gilroy et al., 2018). The application evaluated in Gilroy et al. (2018) also used the Mulberry Symbol Set (Paxton, 2015) as its base set of assets to facilitate easy comparisons to the LT alternative. Consistent with an LT approach, initial icons were sized at 3 × 3 cm by default on the screen and were resized and repositioned as needed.

Delayed Intervention Start Control (Control). Participants assigned to the Control group received no function-based intervention from the study authors for that leg of the trial. Rather, participants in the Control condition continued to receive the eclectic communication training strategies provided by their classroom teachers. No teachers endorsed receiving prior training in PECS from Pyramid Educational Consultants, Inc or in applied behavior analysis. It warrants noting that behavior analytic services and training have grown in adoption in the Republic of Ireland (see Kelly et al., 2019 for a discussion), though opportunities for teacher consultation are much less frequent when compared to North America. As such, communication training practices in the participating sites were not function-based and were best described as a loose collection of eclectic, non-ABA practices. Specifically, participating teachers provided laminated choice boards for all students but these were neither individualized nor was there any planned prompting strategy nor any strategy for systematically removing such prompts (i.e., transferring stimulus control to respective Mos). These boards were typically affixed to classroom structures (i.e., taped to tables and desks), included a common set of referent icons for all students related to classroom activities (e.g., playground, bathroom, sand table), and boards were mostly identical across learners in each classroom (i.e., shared one board during circle time). There were no established methods of data collection related to student communication or student preference linked to the communication training procedures in the classrooms.

Data Analysis Plan

All trial analyses were performed using the R Statistical Program. Linear mixed-effects modeling was performed using the *lme4* R package to evaluate the effect of various factors (e.g., Control vs. AAC, HT vs. LT) on individual responses to communication training. Mixed-effects models philosophically fit within the behavior analytic tradition, wherein the focus is on group-level averages but individual-level variability is also retained for further examination and analysis (see Young, 2018 for a relevant discussion). A linear modeling approach was pursued given the robustness of the methodology even in cases where violations of assumptions might be observed (see Schielzeth et al., 2020, for a relevant discussion and evaluation). Regardless, all models were inspected for linear relationships between communication outcomes and model factors as well as for homogeneity of variance. Across all modeling options, linear mixed-effects models were first compared against generalized least squares (GLS) fits and the utility of random effects (RE) was determined using the Akaike Information Criterion (AIC; Akaike, 1974). For the mixed-effects models, clustering arrangements were evaluated using AIC along with the maximal model arrangement (i.e., all potential interactions included). Following the identification of the optimal RE structure, model selection was performed using Maximum Likelihood fits and Likelihood Ratio Tests (LRTs) to determine which models the data were most likely to emerge from. The *emmeans* package was used to perform supplemental comparisons for each fitted model (i.e., simple main effects; Lenth, 2018).

For the first research question, the *lme4* package was used to compare the overall effects of eclectic (Waitlist Control; i.e., delayed intervention start group) and function-based forms of communication training (AAC) on the combined levels of functional communication observed on pre- and post-intervention BCAs (i.e., both vocal + AAC responses). Naturally, this comparison was restricted to the first leg of the trial because participants in the delayed intervention start group received function-based training in the second leg of the trial. For the second research question, the *lme4* package was used to compare the effects of HT and LT AAC on the combined levels of functional communication observed on pre- and post-intervention BCAs. Given that function-based intervention occurred across both legs of the trial, this analysis was performed using the combined data from both legs.

Results

RQ1: AAC vs. WC

Modeling for RQ1 supported the inclusion of random effects for individual intercepts and slopes for Time. That is, individual-level variability was considerable and the inclusion of random effects improved model performance (i.e., individuals varied in terms of both their starting levels and rates of improvement). Model comparisons using LRTs supported the inclusion of a Time (Pre, Post), Group (WC, AAC), and a Time X Group interaction. There was a significant effect observed for Time ($\beta = 4.0$, $t = 7.24$, $p < .0001$), whereby the overall predicted rates of functional communication increased for the entirety of participants in the first leg of the trial (see Figure 2). However, there was a significant interaction between Time and Group, whereby participants in the AAC group overall demonstrated significantly higher rates of acquisition than the WC group ($\beta = 3.84$, $t = -4.66$, $p < .0001$; see Figure 2). As such, there was a large observed change for the AAC group but not for the WC group.

These effects were further scrutinized using *emmeans* to evaluate the simple main effects for each group, pre- and post-intervention. Results revealed a significant change over Time for the AAC group (estimate = 4.0, $SE = 0.55$, $T = 7.25$, $p = < .0001$) but not for the WC group (estimate = 0.15, $SE = 0.61$, $T = 0.25$, $p = .80$). These results indicate that the absence of function-based programming did not yield an effect (i.e., change in functional communication not significantly different from 0). Individual contrasts across groups at comparable points in the study were explored to confirm that there were not pre-existing differences in communication repertoires at the outset of the trial. Results revealed non-significant differences between the AAC/WC groups at pre-test (estimate = -0.12, $SE = 0.19$, $T = -0.62$, $p = .92$) but significant differences between the two at post-test (estimate = 3.72, $SE = 0.87$, $T = 4.23$, $p < .01$). These findings indicate that overall groupings did not differ significantly at baseline, but following intervention, there was a significant difference across the two at the end of the trial. Although various other factors were included in the model (e.g., sex, age, autism severity), none were significant predictors of improvements in function-based communication.

RQ2: LT-AAC vs. HT-AAC

Modeling for RQ2 supported the inclusion of random effects for individual intercepts and slopes for Time. That is, consistent with RQ1, retaining individual-level variability significantly improved model performance (i.e., highly variable starting levels and improvement rates). Model comparisons using LRTs did not support the inclusion of AAC Type (i.e., HT, LT) as a factor in the analysis (χ^2 (5) = 4.6, $p = .45$) and this indicated that the AAC Type factor was not statistically useful in predicting changes in communication during the study. However, even though AAC Type was a nonsignificant factor, it is retained here due to its central relevance to the research question. Results in the full, unrestricted model indicated a significant effect for Time (β [Post Treatment] = 2.71, SE = 0.61, T = 4.45, $p < .001$), whereby an overall increase in functional communication was observed across all users of function-based AAC following intervention (see Figure 3). Neither AAC Type (β [HT] = 0.32, SE = 0.41, T = 0.78, $p = .43$) nor the interaction between Time and AAC Type (β [Time:HT] = 1.08, SE = 0.84, T = 1.29, $p = .21$) were significant.

These results were reviewed further using the *emmeans* package to evaluate the simple main effects for specific types of AAC pre- and post-intervention. Results revealed a significant change over Time for the LT group (estimate = 2.71, SE = 0.63, T = 4.29, $p = < .001$) and the HT group (estimate = 3.8, SE = 0.61, T = 6.21, $p < .0001$; see Figure 3). These results indicate that both HT and LT AAC overall resulted in improved functional communication but the overall rates of improvement across each were not significantly different across learners throughout the trial. Individual contrasts across groups were not significant at pre- (estimate = -0.32, SE = 0.42, T = -0.76, $p = .87$) or post-test (estimate = -1.41, SE = 0.93, T = -1.50, $p = .44$). These findings indicate that overall groupings did not differ significantly across either point in the trial. Similar to RQ1, other factors were also included in the model, but none were significant predictors of improvements in function-based communication.

Discussion

There continues to be a pressing need to better understand technology and its place in designing applied behavior analytic interventions. Referring back to the guidance provided by Mirenda (2001) two decades ago, the question was never whether more high-tech alternatives would be efficacious—the question was whether or not the technology added some new value to the therapeutic approach. These remarks were prescient, given the time, and modern technology is increasingly included as an element of behavior analytic instruction and intervention. With regards to AAC intervention, despite extensive discussion and debate in both clinical practice and the research literature, there has been a relative paucity of direct research with clear results to inform the debate and guide practice. The goal of the current trial was to contribute critical experimental data to help examine the role and value of technology in AAC intervention and to inform applied clinical and educational behavior analytic practice. Specifically, the current study examined whether the type of intervention approach (e.g., function-based) and/or the level of technology (e.g., high-tech vs low-tech AAC) most contributed to the acquisition of functional and independent communication repertoires. Consistent with the outcomes from Gilroy et al. (2018), the results of this trial overwhelmingly indicated that function-based approaches to establishing communication repertoires most contributed to positive outcomes, and that variations in the type of technology (high-tech, low-tech) did not register statistically meaningful differences overall.

Although the lack of clear and significant differences are rarely represented in behavior analytic venues (see Tincani & Travers, 2019 for a discussion of null findings in behavior analysis), these findings bode well for the function-based behavior analytic perspective and approach, and an emphasis on basic science in this regard. Specifically, teaching approaches based on both established behavior analytic principles and Skinner's taxonomy of Verbal Behavior (Skinner, 1957) more reliably drove treatment effects rather than eclectic classroom-based practices or the simple conveniences offered by a modern multimedia device. That is to say that behavioral intervention based on established principles of behavior was efficacious regardless of whether the topography of the communication response was the press of a screen (and subsequent vocal output) or the exchange of a picture card. Put simply, this trial did not find evidence that one modality of function-based AAC was significantly more or less effective than another. Pragmatically, both the consequence and stimulus conditions are constant in such circumstances, and it stands to reason the intervention outcomes *should* be comparable assuming no device-level barriers. To further illustrate this point, we direct the reader to related efforts leveraging modern technology to facilitate contingency management (Dallery et al., 2013; Dallery et al., 2019). As reviewed in Dallery et al. (2019), technology provides a novel means to increase the access, immediacy, and fidelity of interventions based on established principles of behavior. That is, the factor driving the effect of these technology-assisted approaches is ultimately the contingencies—not the technology. This observed relationship between the science of learning and novel approaches (e.g., emerging technologies) bodes well for the future of behavior analysis in ongoing, translational research and development.

With regards to direct clinical and educational application, the findings from this study indicated that high- and low-tech forms of function-based alternatives did not result in clinically or statistically significant differences. That is, these results indicated that there is limited evidence to suggest that either approach is significantly better or worse for the current population. Given the lack of clear and substantial differences across approaches, the question then shifts to how individual-level factors might factor into outcomes for each form of intervention. Specifically, further investigation is warranted to explore how individual needs and preferences moderate outcomes from varying forms of AAC intervention (see Ganz, 2015). Indeed, embedding opportunities for individual choice for learners is both consistent with behavior analytic values (i.e., increased social validity; Bannerman et al., 1990; Wolf, 1978) and can result in improved behavior in its own right (for a review, see Tullis et al., 2011). It is unclear at this time whether individual preference would lead to consistently different outcomes in the context of AAC intervention, but regardless, such an approach would be consistent with both behavior analytic ethics and commitments to evidence-based practice (Smith, 2013).

Limitations

This study effectively built upon and extended earlier clinical trials which evaluated and/or compared behavior analytic intervention packages, but several limitations warrant noting. First, the population of autistic learners is highly heterogenous and this study focused on a specific subset of that population (i.e., those with autism plus ID). As such, the findings and claims related to efficacy included in this report are restricted to this subset of the autistic population. Second, the verbal operants targeted in this study are not exhaustive and should not be construed as representative of a fully intact and complete social-communicative repertoire (Tincani et al., 2020). That is, communicative repertoires targeted in this study improved as a result of intervention but the short window of time constrained the types of operants targeted (i.e., teaching focused initially on the mand). Third, this study (along with most others in this regard) evaluated outcomes in a relatively brief window of time. As such, the non-significant differences observed in both the current trial and the related Gilroy et al. (2018) trial do not preclude the possibility that there may be differences in the relative impacts of high-tech and low-tech AAC intervention approaches when these interventions are implemented and their impacts examined further longitudinally throughout an individual’s early- and school-age development. Fourth, this study explored various ways in which to establish functional social communication but there was no means of assessing integrity across the various intervention types. Indeed, the pragmatics of implementing community-based trials (i.e., video recording therapists, working with teachers in schools) and challenges associated with characterizing eclectic practices limited the ability of the authors to collect such data. Future investigations in this area would benefit from evaluating treatment integrity as a potential covariate related to AAC intervention outcomes. Fifth, most large trials include complete blinding to conditions but this cannot be fully achieved when observers can visibly see the type of communication approach. Lastly, it warrants noting that the delayed intervention Control and the AAC conditions varied to a small degree in terms of one-to-one intervention time and scheduling and this is a potential limitation. Although function-based approaches are historically considered superior to non-function-based alternatives, the difference between these conditions may have been lessened if one-to-one programming was a feature of the Control group.

Summary

In summary, the results from this community-based delayed intervention start randomized controlled trial indicated that HT and LT AAC intervention resulted in significant improvements over an eclectic non-ABA intervention approach in specialized schools for children with autism and comorbid ID. These findings provide clear and direct support for the critical role of a function-based behavior analytic approach, which in turn overshadows the impact of the specific intervention delivery method (i.e., HT vs LT). The fact that there were no clear or clinically substantial differences in group-level treatment outcomes or individual variability in treatment response for HT versus LT AAC further suggests that the most critical feature of effective AAC programming is an emphasis on function-based intervention. That is, there is limited information to suggest that any particular form of function-based AAC imparts significantly greater or lesser benefit than the other. Given the lack of a clear difference, additional research on individual-level factors (e.g., learner and family preferences) and their relationship to outcomes continues to be necessary. Future directions should explore the potential moderating effect of learner preference, intervention feasibility and acceptability, as well as individual- and device-level factors on outcomes of HT and LT AAC intervention.

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Appendix

Study Power

Study power was calculated using the *simr* package in the R Statistical Program. This package allows for a determination of study power as a function of various expected effects, variances (e.g., random effects), and study parameters (i.e., sample size). Data from the Gilroy et al. (2018) trial were fitted using mixed-effects models and those estimates were used as a guide for the present trial. Lower levels of performance were anticipated and the expected values for the intercept (0.29), Time (4.14), and Type (0.56) were set to 50% of what was observed in the prior trial. Similarly, the standard deviation of residuals (1.26) and random effects (~ ID; 0.97) were also halved using the prior results as a basis. A model was generated with effects of 0.29, 4.14, 0.56, and 2.0 for the intercept, Time, Type, and the Time by Type interaction. Study power was estimated using the *powerCurve* function in *simr* and estimated study power is illustrated in the figure below:

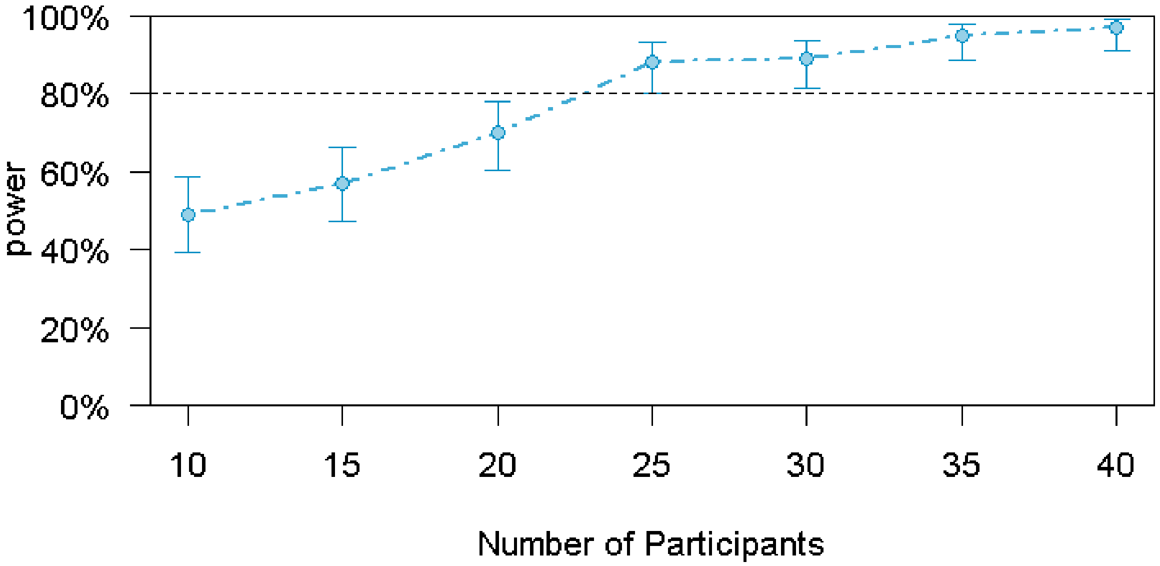


Table 1

Participant Characterization Measures

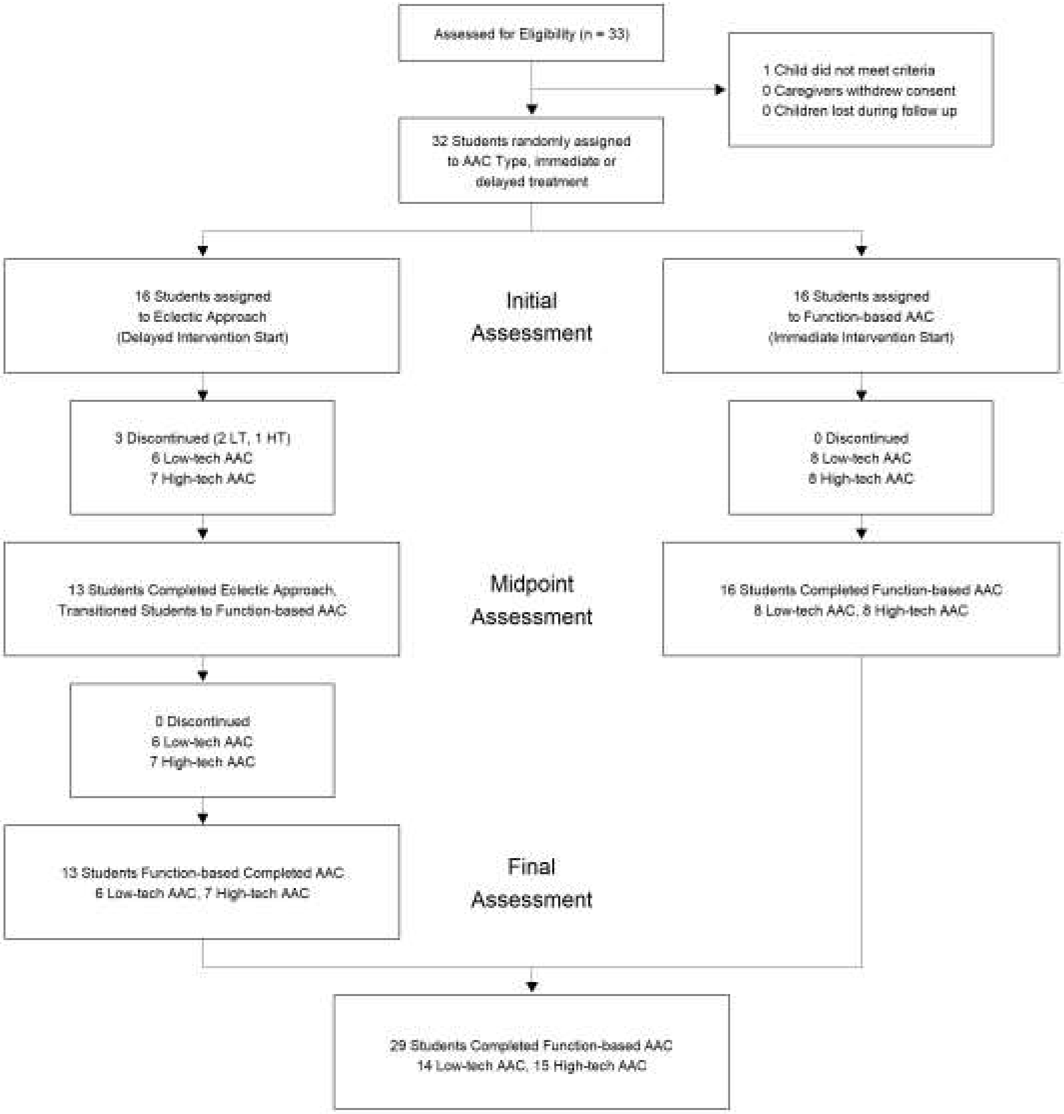
	Overall (*n* = 29)		
Factor	Mean (*SD*)	Median (Mdn)	Q1-Q3
Age	10.44 (*3.25*)	11	7-14
CARS2-ST			
T-Score	52.27 (*10.59*)	53	42-62
Severity	2.51 (*0.68*)	3	2-3
ABAS-3			
Social	2.53 (*2.04*)	1	1-3
Communication	1.96 (*1.79*)	1	1-2
Observed Vocalizations	0.1 (0.3)	0	0-0

	Eclectic Intervention (*n* = 13)			AAC Intervention (*n* = 16)		
Factor	Mean (*SD*)	Mdn	Q1-Q3	Mean (*SD*)	Mdn	Q1-Q3
Age	11.0 (*2.1*)	11	10-12	9.9 (*3.9*)	10	7-14
CARS-ST						
T-Score	52.2 (*11.4*)	56	46-62	50.6 (*9.9*)	53	43-56
Severity	2.6 (*0.6*)	3	2-3	2.4 (*0.7*)	3	2-3
ABAS-3						
Social	3.0 (*2.3*)	3	1-4	2.1 (*1.6*)	1	1-3
Communication	1.7 (*1.4*)	1	1-2	2.1 (*2.1*)	1	1-2

	Low-Tech AAC (PECS; *n* = 14)			High-Tech AAC (SGD; *n* = 15)		
Factor	Mean (*SD*)	Mdn	Q1-Q3	Mean (*SD*)	Mdn	Q1-Q3
Age	10.0 (3.*4*)	10.5	7-13.25	10.8 (*3.1*)	11	9.5-13.5
CARS-ST						
T-Score	51.8 (*11.4*)	53.5	41.5-59.5	52.6 (10.1)	53	44.5-62
Severity	2.4 (*0.8*)	3	2-3	2.6 (*0.5*)	3	2-3
ABAS-3						
Social	2.8 (*2.2*)	2	1-4.5	2.2 (*1.8*)	1	1-3
Communication	2.3 (*1.9*)	1	1-3.5	1.6 (*1.6*)	1	1-1

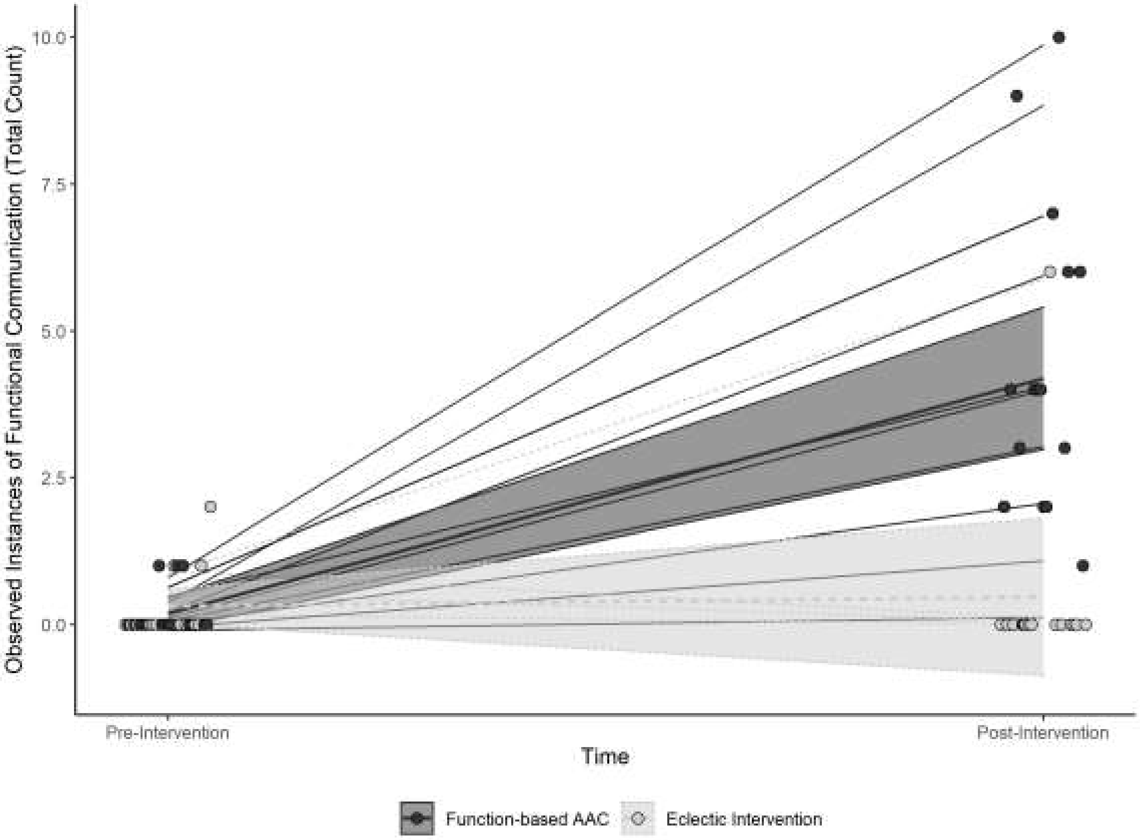
This table depicts the means, standard deviations, and interquartile ranges (i.e., 25th-75th %ile [Q1-Q3]) of study participant across the varying intervention approaches, approaches to AAC, and the characterization of the sample overall.

Figure 1. CONSORT Chart



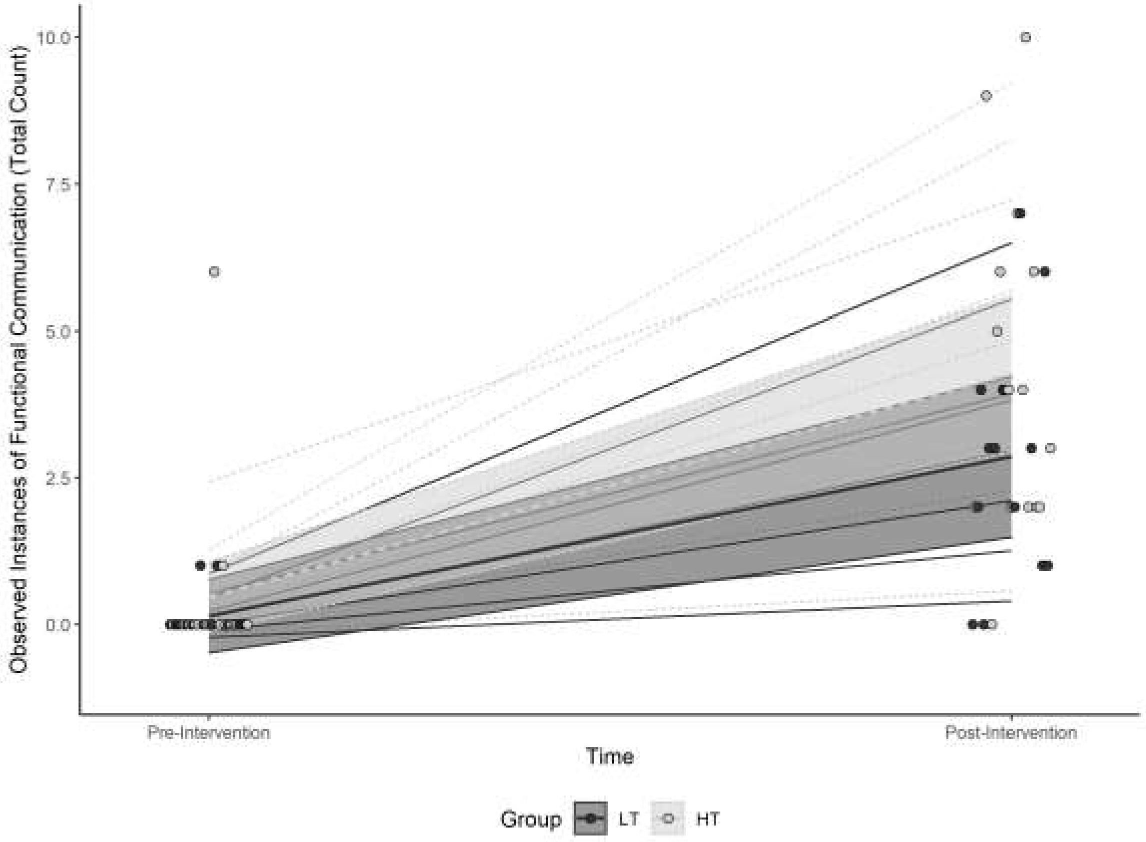
This figure illustrates the planned and executed sequence of the trial. The figure describes the sequence and results of participant recruitment, participant assignment/randomization, and an account of the participants that completed the intervention.

Figure 2. Comparisons of Eclectic and Function-based AAC Approaches



This figure illustrates the differential outcomes for eclectic and function-based AAC intervention (Standardized Within-Group Residuals Mdn [Q1-Q3] = .00 [-.29-0.01]). The ribbons and heavy-shaded lines reflect the fixed effects (along with uncertainty) and the thinner lines reflect the random effects (i.e., individual lines).

Figure 3. Comparisons of HT and LT AAC Modalities



This figure illustrates the varying rates of acquisition for HT and LT forms of AAC intervention (Standardized Within-Group Residuals Mdn [Q1-Q3] = .09 [-.32-0.15]). The ribbons and heavy-shaded lines reflect the fixed effects (along with uncertainty) and the thinner lines reflect the random effects (i.e., individual lines).