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THE ADDED EFFECT OF VISUAL SCENE DISPLAY AAC WITHIN A NATURALISTIC DEVELOPMENTAL BEHAVIORAL INTERVENTION FOR YOUNG CHILDREN ON THE AUTISM SPECTRUM WITH MINIMAL SPEECH

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Lauramarie Pope

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The dissertation of Lauramarie Pope was reviewed and approved by the following:

Janice C. Light
Professor of Communication Sciences and Disorders
The Hintz Family Endowed Chair in Children's Communicative Competence
Dissertation Advisor
Chair of Committee

Diane L. Williams
Professor of Communication Sciences and Disorders
Head of the Department of Communication Sciences and Disorders

Jessica Caron
Assistant Professor of Communication Sciences and Disorders

David Lee
Professor of Education

ABSTRACT

Many children on the autism spectrum[1] struggle significantly in their early language development, entering kindergarten with little or no functional speech (Kasari et al., 2014; Rose et al., 2016). Naturalistic developmental behavioral interventions (NDBIs) are a promising approach for supporting early language and communication development for young children on the autism spectrum (e.g., Sandbank et al., 2020). NDBIs blend developmental principles with behavioral intervention strategies within naturalistic environments to support child development across domains (Schreibman et al., 2015). However, the children with the greatest need of language supports – those with minimal speech – have limited means to participate within these interventions and are therefore the least likely to benefit from traditional NDBIs that focus primarily on speech production (Kasari et al., 2014).

Augmentative and alternative communication (AAC) offers children on the autism spectrum with limited speech the potential means to enhance communication and participate effectively in the interactions needed to support early language and communication development. To date, only one study has directly investigated the impact of adding traditional, grid-based AAC supports into a preexisting NDBI, with promising results (Kasari et al., 2014). However, grid-based AAC systems can still constrain access to contextually-relevant and motivating vocabulary, effectively limiting critical language learning opportunities. No research has explored incorporating AAC systems that have been specifically designed to support early language and communication development into the context of an NDBI.

The proposed study aimed to fill this gap by investigating the effect of integrating visual scene display (VSD) AAC supports with "just-in-time" programming and aided AAC input within an NDBI framework for young children on the autism spectrum with minimal speech. VSD systems capture the

[1]Participating caregivers were asked their preferences regarding terminology when referring to their participating child's autism diagnosis. All caregivers were comfortable with "child on the autism spectrum," so this terminology is used throughout the manuscript. This terminology has also been considered acceptable by autistic adults (Bury et al., 2020). However, the author also acknowledges that many autistic adults prefer identity-first language (Bury et al., 2020) and supports using language that aligns with the preferences of the individual person(s) being described.

contexts in which language is learned and used through photographs, embed vocabulary within these familiar scenes, and support quick and easy programming of new vocabulary during interactions in response to children's interests (Holyfield, Caron, & Light, 2019). These systems give children access to dynamic, contextually relevant, and motivating vocabulary, supporting active engagement within early language learning contexts. In addition, aided AAC input consists of communication partners augmenting their own spoken input by selecting relevant vocabulary on the aided AAC system (O'Neill et al., 2018). Strong evidence indicates that aided AAC input is highly effective in supporting communication and vocabulary development for individuals with limited speech (O'Neill et al., 2018).

Using a single case, multiple-probe across participants design, the current study investigated the impact of adding VSD-based AAC supports with just-in-time programming and aided AAC input into NDBI procedures on the total number of symbolic communicative turns taken during 10-minute interactions by young children on the autism spectrum with minimal speech. The following collateral variables were also explored: (a) the cumulative number of unique vocabulary concepts expressed; (b) the communication modality of symbolic turns expressed by participants (e.g., speech, gestures, aided AAC); (c) characteristics of the most frequent expressive vocabulary concepts; (e) characteristics of vocabulary programmed just-in-time in response to participants' interests; and (f) comprehension of the spoken word for book-related concepts. Results of a caregiver social validity questionnaire are also reported.

Participating children were all in the First Words stage of language development (as defined by Tager-Flusberg et al., 2009), indicating that they were in the process of developing an initial corpus of single word expressive communication. During this period of language development, acquiring a robust vocabulary and developing formative social communication skills is critical to establishing the essential building blocks needed to support later language growth, such as word combinations.

Participant performance in baseline on (a) the number of symbolic communicative turns per session, (b) the cumulative number of unique vocabulary concepts expressed, and (b) the communication modality of symbolic turns was compared to intervention, with the addition of VSD AAC supports and aided AAC input. All participants tended to take more turns each session and add new expressive vocabulary more rapidly in intervention than in baseline, though with notable variation across participants. Participants generally communicated most frequently using gestures in baseline and aided VSD AAC during intervention, with no notable change in the low rates of speech production across phases. Overall, the ten most frequent expressive vocabulary concepts for each participant consisted mostly of nouns, though with a notable number of verbs. However, interjections (e.g., "Oh, no!" "Wheee!") were also often at the top of participants' high frequency vocabulary lists. Vocabulary programmed just-in-time also consisted primarily of nouns. Lastly, participants performed at chance levels identifying the spoken words for book-related vocabulary pre-selected by the researcher across study phases. However, for half of the participants, accuracy was above chance levels on a post-hoc individualized comprehension measure of spoken language that targeted the vocabulary concepts communicated most frequently by each participant (50-70% accuracy).

The results of this study indicate that including VSD-based aided AAC systems and strategies designed to support beginning communicators within the framework of an NDBI can increase both the communication frequency and expressive vocabulary of children on the autism spectrum with minimal speech, beyond the effects of NDBI procedures alone. Additionally, these results demonstrate that, when given greater agency over their communication, the expressive vocabularies of children on the autism spectrum with minimal speech in the First Words stage of language development consist predominantly of nouns, with some concrete verbs and interjections, as is common in early language development of neurotypical children who use speech (McDonough et al., 2011). Lastly, study outcomes suggest that the connection between expressive use of aided AAC vocabulary and understanding of the spoken word is complex, requiring further investigation. These results demonstrate the positive impact of intervention strategies that combine the strengths of NDBIs and developmentally appropriate AAC intervention on both social pragmatic (turn taking) and semantic (vocabulary growth) development. In addition, this study lays the foundation for future research expanding NDBI and AAC research into new contexts, with a

variety of communication partners, and with more fine-grained comparisons between intervention components.

Keywords: augmentative and alternative communication, autism, beginning communicators, naturalistic developmental behavioral interventions

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Chapter 1

Introduction and Review of the Literature

Early language and communication development in children on the autism spectrum

Many children on the autism spectrum struggle to meet their basic communication needs via spoken language (Tager-Flusberg et al., 2005). By kindergarten entry – when most neurotypical children are already using complex language – approximately 25-30% of children on the autism spectrum use little or no speech (Kasari et al., 2014; Rose et al., 2016). Without access to speech, these children are unable to participate in vital language learning opportunities. They cannot try out new vocabulary modeled by communication partners, and thus miss out on feedback on their own utterances, as well as exposure to related concepts through expansions by communication partners. Young children on the autism spectrum generally tend to use both less speech and fewer gestures during interactions with their caregivers than neurotypical children (Delehanty & Wetherby, 2021). Additionally, evidence suggests that the complexity of caregiver input for young children with early signs of autism is influenced by the mean length of expressive utterance of the children themselves (Smith et al., 2022). Thus, children with minimal speech are likely receiving less robust language input than their peers with more developed expressive communication. These cumulative factors put children on the autism spectrum with minimal speech at significant risk in terms of developing the diverse initial vocabulary needed to support later word combinations, negatively impacting long-term language trajectories (Tek et al., 2014).

By definition, challenges with social communication are characteristic of autism (American Psychiatric Association, 2013). However, social communication and language development are inherently interdependent (Prelock & Nelson, 2012). Social interaction with caregivers provides the context for early language learning. Thus, children on the spectrum who have lower rates of reciprocal joint engagement with their communication partners tend to have less robust expressive language growth (Bottema-Beutel et al., 2014). In turn, when children use less expressive speech themselves, the complexity of language input from their caregivers may be reduced (Smith et al., 2022). As caregiver responsiveness to children's communication is also predictive of later vocabulary development (McDuffie & Yoder, 2010), this constellation of factors may have a cascading negative effect on language and communication development for young children on the autism spectrum with minimal speech. Furthermore, frustration as a result of communication challenges may manifest as challenging behavior (Drager et al., 2010; Muharib et al., 2019), creating yet another barrier to positive social engagement, communication, and opportunities for language learning. Effective, evidence-based intervention strategies are urgently needed that not only target joint engagement and social communication, but actively integrate supports for early language and communication development for children on the autism spectrum with minimal speech, in order to provide the essential building blocks for long-term language and communication success.

Naturalistic developmental behavioral interventions

Naturalistic developmental behavioral interventions (NDBIs) offer one promising avenue to support early development across a variety of skills for children on the autism spectrum. NDBIs incorporate the strengths of both behavioral learning and developmental perspectives into naturalistic routines and environments (Schreibman et al., 2015). The core components of NDBIs include: (a) the type and progression of skills that are targeted, (b) the contexts in which intervention takes place, and (c) the strategies used to promote growth across learning domains (Schreibman et al., 2015).

NDBIs are designed to target skills across developmental domains (e.g., language, social, cognition, motor, play), as opposed to focusing on a single skill – or domain – in isolation (Landa et al., 2011). Additionally, the goal of NDBIs is integration of skills across domains and contexts (Schreibman et al., 2015). For example, using a new expressive language concept to engage with a communication partner (as opposed to discrete object identification), or using a new motor skill (e.g., clapping) within a play routine. NDBIs also focus on a developmental sequence of skill acquisition (Schreibman et al., 2015), targeting skills in one domain (e.g., joint engagement) that build and intersect with other skills within and across domains (e.g., attention, expressive language) to support an integrated developmental cascade.

NDBIs are designed to be situated within the context of a child's natural environment and routines (Schreibman et al., 2015), aligning with the integrated nature of intervention goals. Additionally, NDBIs put the focal point on activities that are interactive and meaningful, providing intrinsic support for social-communication development (Schreibman et al., 2015). A naturalistic, interactive setting allows intervention to be more child-directed (as it occurs within a familiar environment/routine and can be shaped by either communication partner), supports the use of natural contingencies (e.g., looking toward a communication partner and then getting their attention), facilitates skill integration across domains (e.g., combining motor, social, and language skills during play), and promotes generalization (as it is already occurring in the natural environment in a meaningful activity).

The overall goal of NDBIs is to provide a framework for successful and continued learning, as opposed to only narrowly targeting individual skills (Schreibman et al., 2015). The focus is to promote high levels of success within interactive contexts, increasing the child's participation and independence over time. Thus, NDBIs use a range of behavioral strategies across target domains (e.g., modeling, shaping, prompting, expanding, reinforcement) to support a child's success in completing functional, integrated skills within naturalistic routines (Schreibman et al., 2015). For example, in a play cooking activity, a communication partner might model cracking an egg. If the child imitates that action by bringing their hands together, the communication partner can shape the child's communication and provide language input by labeling the action ("Crack!"). The communication partner can then expand the language input (e.g., "Crack the egg!") and the play routine (e.g., mixing the egg). As the child becomes more familiar with the routine, they might be prompted to ask for a turn to mix the eggs and receive natural contingent reinforcement by having a turn at mixing.

The term "NDBI" was created in large part to reflect the presence of these underlying core components within a variety of established interventions, many of which target young children on the autism spectrum specifically (Schreibman et al., 2015). Some of the most prominent of these interventions include incidental teaching (Hart & Risley, 1968), Pivotal Response Training (PRT; Koegel et al., 1989), the Early Start Denver Model (ESDM; Dawson et al., 2010), Enhanced Milieu Teaching (EMT; Kaiser & Hester, 1994), Project ImPACT (Improving Parents As Communication Teachers; Ingersoll & Wainer, 2013a), Joint Attention Symbolic Play Engagement and Regulation (JASPER; Kasari et al., 2006), and Early Achievements (EA; Landa et al., 2011; Schreibman et al., 2015). However, intervention procedures that do not specifically follow one of these preexisting protocols may still qualify as an NDBI, given that they occur in a natural context, include this same balance of developmental principles (e.g., developmental progression of skills, integrated goals across domains) and behavioral strategies (e.g., prompting, modeling, shaping, expanding), and employ natural contingencies (Tiede & Walton, 2019). Additionally, though all NDBIs have these same core components, they vary in their specific procedures, including the target audience, primary skill domains, and recommended activities. For example, Project ImPACT was specifically designed to train caregivers to support their child on the autism spectrum, while other NDBIs are targeted at professionals (though many have also been later adapted for caregivers as well). JASPER and EA both have a focus on joint attention, while EMT emphasizes language. Incidental teaching and PRT both highlight increasing motivation (often through environmental arrangement), while ESDM puts a strong focus on the relationship between the child and communication partner. However, all share those same core components of targeting a range of developmental domains, integrating intervention into naturalistic contexts, and incorporating both developmental principles and behavioral strategies.

Evidence supports the effectiveness of NDBIs for young children on the autism spectrum, across a variety of developmental domains (Crank et al., 2021; Sandbank et al., 2019; Sandbank et al., 2020; Tiede & Walton, 2019). Meta-analyses indicate that NDBIs can promote increases in the domains of social communication, language, play, and overall cognitive development (Crank et al., 2021; Sandbank et al., 2019; Tiede and Walton et al., 2019). Additionally, when taking research quality into consideration, NDBIs appear to have stronger cumulative empirical evidence supporting their effectiveness across domains, as compared to other common intervention methods designed for young children on the autism spectrum (e.g., developmental approaches, behavioral approaches, TEACCH; Sandbank et al., 2019) – though this difference may not be as stark for language targets specifically (Sandbank et al., 2020).

NDBIs and language

Cumulative evidence suggests a positive impact of NDBIs on the language development of young children on the autism spectrum (Pope et al., 2023; Sandbank et al., 2019; Sandbank et al., 2020; Tiede & Walton, 2019). This includes evidence for both receptive and expressive language outcomes, as well as both language skills targeted directly in the intervention and standardized language assessment performance (Pope et al., 2023; Sandbank et al., 2020; Tiede & Walton, 2019). Aggregate effect size estimates vary across meta-analyses, but suggest at least a small, though statistically significant, effect of NDBIs on language, ranging from 0.18 – 0.74 (Hedge's *g*; Pope et al., 2023; Sandbank et al., 2019; Sandbank et al., 2020; Tiede & Walton, 2019). Additionally, NDBI methods also appear to support social communication development (aggregate Hedge's $g = 0.42$; Sandbank et al., 2019), potentially increasing the language learning opportunities available to children on the autism spectrum, as a result of increasing joint engagement with communication partners.

However, children on the autism spectrum with minimal speech are less likely to benefit from NDBIs in their traditional format (Kasari et al., 2014). Without speech, these children have limited means to engage in the rich language learning environment of NDBIs. One study found that even with relatively intensive intervention (2 hours per week over the course of 12 weeks), 40% of children with limited speech did not make substantial progress when exposed to established NDBI strategies (Kasari et al., 2014). In fact, the evidence suggests that children with greater preexisting language skills experience more significant language growth over the course of intervention than those with less advanced skills (Sandbank et al., 2020). Though NDBI methodologies appear effective for increasing language and communication for children on the autism spectrum more generally, they may be less effective in their traditional format for those children with the greatest communication needs – children on the autism spectrum with minimal speech.

Augmentative and alternative communication

Augmentative and alternative communication (AAC) offers potential tools to support the early language and communication development of young children on the autism spectrum with minimal speech. AAC includes any means of communication other than speech, ranging from unaided methods (e.g., gestures, sign language, facial expressions) to aided systems (e.g., letter boards, speech generating apps on a tablet, picture exchange).

Aided AAC has a strong evidence base for supporting the language and communication skills of children on the autism spectrum (Ganz et al., 2011; Ganz et al., 2012). Cumulative effect sizes across studies suggest a medium to large effect of all aided AAC modalities on communication measures generally, across age ranges and level of autism characteristics (IRD = 0.7-0.99; Ganz et al., 2011; Ganz et al., 2012). Both low-tech (e.g., picture exchange) and high-tech (e.g., speech generating device) AAC interventions have shown significant positive effects on communication (IRD = 0.99 for both; Ganz et al., 2012). These studies have almost exclusively measured expressive communication (Ganz et al., 2011; Ganz et al., 2012). Additionally, the majority of AAC research with children on the autism spectrum has focused primarily on object requesting, followed by reducing challenging behaviors, with significantly less attention to other communicative functions or social interaction (Ganz et al., 2011; Ganz et al., 2012). In fact, even among studies focused more directly on social communication outcomes, almost three quarters also included object requests as a target of intervention (Logan et al., 2017). However, those AAC intervention studies that have focused on social communication skills similarly demonstrate high rates of success (aggregate IRD = 0.9; Ganz et al., 2012). As challenges with social interaction are characteristic of children on the autism spectrum, AAC interventions that focus on supporting shared engagement and social communication are essential.

NDBIs and AAC

The integration of aided AAC into NDBI strategies may be a powerful pairing to maximize both language and communication growth – as well as social communication specifically – for young children on the autism spectrum with minimal speech. Though many manualized NDBIs (e.g., JASPER, Early Achievements) do place an emphasis on deictic gestures (e.g., pointing for joint attention) and gestural imitation, these basic forms of unaided AAC do not appear to be sufficient to support the early language and communication growth of children with minimal speech (Kasari et al., 2014).

To date, only one study has directly compared the added impact of including aided AAC into NDBI procedures to NDBI strategies alone. Kasari et al. (2014) used a sequential multiple assignment randomized trial design to explore the effect of incorporating aided AAC within a manualized NDBI (a combination of JASPER and EMT) on a variety of language and communication outcomes for children on the autism spectrum ages five to seven. Results indicated that if participants had access to aided AAC from the start of intervention, they demonstrated significantly higher rates of socially communicative utterances and comments, and used a significantly greater variety of words than those participants who did not have access to aided AAC initially (Kasari et al., 2014). These differences remained strikingly consistent throughout the course of the study, measured at weeks 12, 24, and 36 (Kasari et al., 2014).

Importantly, if participants were only provided with aided AAC partway through the study, their language and communication growth was not as robust as those who had access to aided AAC from the start (Kasari et al., 2014). However, all participants who had access to aided AAC at some point during the study had statistically significantly greater language and communication outcomes than those who did not have access to aided AAC. It is critical to note that participating children (ages 5-7) were already beyond the critical initial language learning period of early childhood. Neurotypical children who use speech are holding conversations and employing complex sentence structure by age five (Singleton & Ryan, 2004). Evidence suggests that access to aided AAC intervention may have a larger impact on the language and communication of young children on the autism spectrum in their preschool years than later in development (Ganz et al., 2011). It is critical that children on the autism spectrum who are at risk for speech and language delays have access to both effective intervention practices (e.g., NDBIs) and effective communication supports (e.g., aided AAC) as early as possible, to maximize early language growth and support positive long-term outcomes (Tek et al., 2014).

The results of Kasari et al. (2014) are promising, demonstrating the need for further research. Kasari et al. (2014) provide strong evidence that when aided AAC is included as an active ingredient in NDBIs, the language and communication growth of children on the autism spectrum with minimal speech is significantly bolstered – over and above the effects of NDBI procedures alone. Importantly, a growing body of research indicates that AAC intervention bolsters speech outcomes (Binger et al., 2008; Millar et al., 2006), as opposed to impeding speech development, including in the context of an NDBI specifically (Kasari et al., 2014).

In addition, recent aggregate evidence similarly suggests that interventions incorporating both NDBI principles and aided AAC may have stronger effects on language and communication growth for young children on the spectrum with delayed speech than NDBI procedures alone (Pope et al., 2023). Pope et al. (2023) completed a review of 29 studies, comparing traditional NDBI research that did *not* include aided AAC to studies that qualified as NDBIs and included aided AAC, investigating the outcomes on language and communication. All participants were 13 years old or younger, with three quarters of the participants between two and five. All participants were reported to have significant speech and language delays, with many described as using little or no speech (Pope et al., 2023). Most studies reported using a specific manualized NDBI (72%), including incidental teaching, EMT, JASPER, PRT, Project ImPACT, ESDM, and EA (Pope et al., 2023). For those studies that included aided AAC, all AAC systems were either high-tech grid-based speech generating devices (70%), picture exchange (20%), or a low-tech grid-based topic board (10%; Pope et al., 2023). Results aligned with previous research, indicating that NDBIs alone can have a positive impact on language and communication outcomes for young children on the autism spectrum (aggregate effect sizes: Tau-U = 0.76 for the single-case studies;

Cohen's $d = 0.74$ for group studies). However, studies that included aided AAC within NDBI procedures had an overall larger positive effect on participants' language and communication outcomes (aggregate effect size: Tau-U = 0.84 for the single-case studies), in line with results from Kasari et al. (2014). These results further emphasize the potential for adding aided AAC within NDBIs to maximize the language and communication growth of young children on the autism spectrum with minimal speech.

The research clearly demonstrates the importance of aided AAC for young children on the autism spectrum with minimal speech; however, most manualized NDBIs target spoken language almost exclusively. Even the most recently published guidelines for JASPER (one of the interventions used in Kasari et al., 2014) only include aided AAC as a follow up option, if traditional NDBI methods prove ineffective (Kasari et al., 2021) – despite results indicating the importance of introducing aided AAC from the outset of intervention (Kasari et al., 2014). Without the means to fully participate actively within NDBI procedures, these children with the greatest needs make the fewest gains (Kasari et al., 2014).

The small corpus of research focusing on incorporating aided AAC within NDBI procedures (including Kasari et al., 2014) has exclusively utilized traditional, grid-based AAC systems or picture exchange (Pope et al., 2023), in which vocabulary is pre-set in advance of interactions. These technologies decontextualize vocabulary by organizing concepts into grids of separate symbols, and generally represent language concepts using abstract line drawings. Evidence suggests that these traditional, grid-based AAC systems can be challenging for both neurotypical young children (Trudeau et al., 2014), as well as older children who use AAC (Sutton et al., 2022) to learn and use. Additionally, vocabulary in these systems is typically pre-programmed in advance of interactions. This limits opportunities for communication partners to capitalize on child interests during interactions to support motivating, in-the-moment expressive vocabulary growth. Responsive communication partner input is key to language development, as it is how young children access new, relevant vocabulary in their environment (Warren & Brady, 2007). Without the ability to add vocabulary quickly and easily to the AAC system in the moment, communication partners are relegated to modeling language only through speech, or only using the vocabulary already available in the system. As a result, children with minimal speech do not have the means to try out new language expressively, receive feedback on their own expression, and be exposed to additional, related language input via communication partner expansions.

Visual scene display AAC with just-in-time programming

Young children who are in the early stages of language and communication development may benefit from AAC technologies that (1) represent vocabulary concepts within the contexts in which they are learned and used, to support comprehension, and (2) allow for the addition of vocabulary in the moment in response to child interests, to motivate vocabulary learning (Holyfield, Caron, & Light, 2019; Light et al., 2019). Visual scene display (VSD) AAC systems with "just-in-time" programming present one potential solution. These systems allow communication partners to capture the contexts in which language is learned and used in the moment, giving children access to relevant and motivating vocabulary right when it is needed (Holyfield, Caron, & Light, 2019; Light et al., 2019).

VSDs use digital photographs to capture language within the context of familiar, meaningful events, supporting comprehension and motivation (Holyfield, Caron, & Light, 2019; Light et al., 2019). Embedding vocabulary concepts within a familiar scene can also reduce joint attention demands and support comprehension of new vocabulary by representing concepts in a way that mirrors real-life experience – while simultaneously providing a tool for expressive communication (Holyfield, Caron, & Light, 2019; Light et al., 2019). VSDs have also been shown to attract the visual attention of individuals on the autism spectrum to the key people and activities within an event, which are the vocabulary concepts that typically emerge early in language development (Light et al., 2019; Wilkinson & Light, 2014).

Research indicates that VSD AAC systems with just-in-time programming are effective for supporting early language and communication development for young children with developmental delays (Light et al., 2012). The participants in Light et al. (2012) were all between 2-5 years old with developmental delays and complex communication needs and had access to either a VSD AAC system that supported just-in-time programming, or a VSD system that did not, in alternating sessions. Participants took significantly more symbolic communicative turns and had access to a larger array of vocabulary during sessions that included just-in-time programming, as compared to sessions that did not (Light et al., 2012). This suggests that beyond the supportive features of VSDs themselves, the ability to program new vocabulary quickly and easily in response to children's interests also has a significant positive effect on communication rates and vocabulary access for young children with developmental delays who benefit from AAC.

VSD AAC technology with just-in-time programming has also been shown to support an increase in communication frequency for older beginning communicators (school age children, adolescents, and young adults; Drager et al., 2019; Holyfield, Caron, Drager, & Light, 2019). All participants in these two studies significantly increased the number of symbolic communicative turns taken per session when VSD AAC systems with just-in-time programming were introduced during familiar leisure activities.

However, previous VSD AAC just-in-time programming research has not focused on young children on the autism spectrum. Importantly, the evidence suggests that programming VSDs during communicative interactions is accessible and efficient for communication partners (Caron et al., 2016; Holyfield, Caron, & Light, 2019), and thus could potentially be incorporated into existing NDBI frameworks without adding significant demands. Quick and easy programming of vocabulary within the context of ongoing interactions can provide access to relevant, motivating, and dynamic vocabulary to support engagement and participation.

Aided AAC input

VSDs provide a supportive context for early language development, but modeling and expansion of language by communication partners are also critical to build vocabulary. For all early language learners, access to new vocabulary and critical cues about its meaning and use come through models by communication partners. Young children who use speech are exposed to new language concepts through their communication partners' spoken utterances and are then able to try out these new words themselves via that same modality (speech), receiving feedback and expanded spoken language input from partners. However, when young children who use AAC are only provided with speech input, there is an asymmetry between the mode of their language input (speech) and language output (AAC; Smith & Grove, 2003). This creates barriers to both language learning and communication by limiting a child's opportunity to use new vocabulary expressively if they have only encountered this vocabulary via speech. Children require exposure to expressive language models in order to learn the AAC vocabulary that is included within their system as they do to learn speech.

Aided AAC input is a powerful instructional tool for supplying these essential language learning opportunities within natural, interactive contexts, using the same expressive communication mode as the child. This strategy consists of communication partners augmenting their own spoken input by selecting relevant vocabulary on the AAC system (O'Neill et al., 2018). Thus, the child receives language input from the partner that aligns with the child's language output (via AAC), providing a direct model of expressive language output.

Strong evidence indicates that aided AAC input is highly effective in supporting vocabulary development for individuals with limited speech (O'Neill et al., 2018). A meta-analysis by O'Neill et al. (2018) found that interventions that included aided AAC input had a very large effect on language and communication outcomes from toddlerhood through adolescence (Tau-U = 0.83-0.9). This very large effect remained consistent across communication partners, including various professionals, parents, and peers (Tau-U = 0.84-0.97; O'Neill et al., 2018). Large to very large effects were observed for both expression and comprehension (Tau-U = 0.84, 0.76), as well as high-tech and low-tech AAC systems (Tau-U = 0.88, 0.79; O'Neill et al., 2018). There was also a large to very large impact of aided AAC input across language domains, including pragmatic, semantic, and morphosyntactic goals (Tau-U = 0.76, 0.85, 0.93; O'Neill et al., 2018). The positive effects of aided AAC input could even be seen after only a short amount of intervention time (less than an hour of intervention: Tau-U = 0.9; O'Neill et al., 2018). Clearly, aided AAC input is a powerful intervention ingredient in promoting language and communication growth for people who use AAC.

Shared storybook reading

As noted previously, most of the prior research exploring the effectiveness of aided AAC for young children on the autism spectrum has targeted requests. These interactions tend to be focused on obtaining a desired object or activity; they are typically not sustained over multiple turn exchanges and do not provide many opportunities for language learning or social communication development. Cumulative evidence suggests that shared reading can be an effective activity for supporting comprehension, communication, and engagement for young children on the autism spectrum who use AAC (Boyle et al., 2019). Shared storybook reading offers opportunities for interactive routines, but within the scaffolded support of the storybook setting, and has been a successful context to support language and communication growth for both NDBIs (Engelstad et al., 2020) as well as VSD intervention for children with developmental disabilities (Light et al., 2012). In addition, storybook reading naturally encourages a greater focus on social communication, providing a shared context for joint engagement, commenting, interactive routines, and turn-taking, in contrast to interactions for object requesting. Lastly, storybook reading provides a supportive context for displaced talk (i.e., communicating about something other than the immediate environment), a critical step in language development (Hockett, 1960). Thus, shared storybook reading may be a particularly powerful activity to promote both language and communication development for young children on the autism spectrum.

Digital books

Research indicates that digital storybooks with integrated AAC features are a supportive context for shared interactions for both young children with developmental delays (Boyle et al., 2021) as well as children on the autism spectrum specifically (Mandak et al., 2019). In addition, digital books offer several potential advantages as a context for intervention, as compared to physical print books paired with a separate AAC system. Potential joint attention demands are minimized, as children do not need to shift attention between a physical book, a communication partner, and the separate AAC system. This is especially notable for children on the autism spectrum, who may experience challenges with joint attention (Adamson et al., 2019).

Study objectives and research questions

The established evidence base highlights the positive impacts of both NDBIs and AAC interventions on the early language and communication development of young children on the autism spectrum. However, minimal research has bridged these intervention domains. No published studies have directly explored the impact of incorporating VSD-based AAC technology with just-in-time programming within an NDBI framework on the early language and communication of young children on the autism spectrum with limited speech. The proposed study aimed to fill this gap by addressing the following primary research question: What is the added effect of incorporating VSD AAC supports with just-in-time programming into NDBI procedures, in conjunction with aided AAC input, during naturalistic routines (specifically interactive shared storybook reading) on the number of symbolic communicative turns taken per session by young children on the autism spectrum with minimal speech?

Given the strong evidence base demonstrating the positive effects of NDBIs on the language development of children on the autism spectrum (Sandbank et al., 2020), it was expected that participants might experience some benefit from NDBI procedures alone. However, in line with previous research (Kasari et al., 2014), it was hypothesized that adding VSDs and aided AAC input into NDBI sessions would significantly increase the total number of symbolic communicative turns taken by children on the autism spectrum with limited speech, above and beyond the effect of NDBI procedures in baseline alone.

The study also addressed the following secondary research questions: what is the effect of adding VSDs with just-in-time programming and aided AAC input into NDBI procedures on (a) the cumulative number of unique vocabulary concepts expressed and (b) the expressive communication modes (e.g., speech, symbolic gestures, aided AAC) of children on the autism spectrum with minimal speech?

It was hypothesized that participants would show a small degree of growth in their number of unique vocabulary concepts expressed in baseline, via imitation of symbolic signs/gestures modeled by the researcher as a part of the NDBI. However, participants were expected to plateau in the number of unique vocabulary concepts expressed in baseline, given the finite number of signs/gestures performed by the researcher. It was further hypothesized that participants would demonstrate a significant increase in the rate of unique vocabulary growth during intervention – as compared to baseline – with access to VSD AAC, just-in-time programming, and aided AAC input. VSD AAC systems allow communication partners to capture the contexts in which language is learned and used in the moment, giving children access to relevant and motivating vocabulary right when it is needed (Holyfield, Caron, & Light, 2019; Light et al., 2019). Just-in-time programming supports communication partners' responsiveness to the child, providing access to relevant vocabulary input and expression in the moment. Thus, the additional contributions of these factors were expected to accelerate expressive vocabulary growth.

Participants were expected to communicate predominantly using symbolic gestures during baseline, with potentially a small number of speech approximations. It was hypothesized that participants would rely mostly on VSD aided AAC during intervention, with a possible reduction in gesture use, given that children on the autism spectrum tend to experience greater success with aided AAC than unaided methods (e.g., manual sign; Lorah et al., 2022). However, rates of speech production were expected to remain similar across study phases, as access to AAC does not show evidence of inhibiting the use of speech (Millar et al., 2006; Schlosser & Wendt, 2008).

The study also explored the following additional outcome variables: (1) the characteristics of participants' most frequent expressive vocabulary concepts (e.g., parts of speech); (2) the characteristics of vocabulary programmed just-in-time (e.g., number of words programmed, parts of speech); and (3) participants' comprehension of the spoken word for book-related concepts. Lastly, the study explored caregiver perceptions of the intervention.

It was hypothesized that participants would communicate noun concepts most frequently, along with a few concrete verbs, as nouns are most prevalent in the early vocabularies of young children who are initially developing language (McDonough et al., 2011). It was also anticipated that participants would communicate a high proportion of vocabulary programmed just-in-time (as compared to preprogrammed vocabulary), as these concepts may better reflect participant interests in the moment than vocabulary pre-selected to target by the researcher. Similarly, vocabulary programmed just-in-time was expected to be predominantly nouns, in relation to their prevalence in early language development (McDonough et al., 2011). In addition, given the imageability of nouns within the book illustrations, it was also most likely for the researcher to be primed to interpret participant interests (most often communicated by the participant touching a part of the book page) as referring to the noun referent depicted.

Participants' comprehension of the spoken word for book-related concepts was measured prior to study initiation, following baseline, and at the end of intervention. It was hypothesized that participants would experience a moderate increase in their performance on this comprehension measure from pre- to post-baseline, but a larger increase in performance by the end of intervention. Traditional NDBI procedures (without aided AAC) have been shown to have a small effect on receptive language (Pope et al., 2023; Sandbank et al., 2020; Tiede & Walton, 2019). However, evidence indicates that general AAC intervention that includes aided AAC input as a component has a large effect on receptive language (O'Neill et al., 2018). Thus, participants were expected to demonstrate larger gains in their comprehension of book-related spoken words with the inclusion of VSD AAC and aided AAC input.

Overall, it was expected that the addition of VSD AAC, just-in-time programming, and aided AAC input would have a strong positive effect on the communicative turns taken and unique vocabulary expressed by young children on the autism spectrum with minimal speech – above and beyond the impact of NDBI procedures alone.

The long-term objective of this research is to establish evidence-based practice for young children on the autism spectrum who have the greatest language impairments and the least positive long-term outcomes (Chamak & Bonniau, 2016). This population has often been overlooked in the research to date. As a result, clinicians and families have little guidance in how best to support these children. Without access to effective interventions that allow them to participate in early language learning experiences, children on the autism spectrum with limited speech are at significant risk in their overall language development, access to education, and social development (Light & McNaughton, 2012), with long-term negative consequences for social functioning, independent living, and employment in adulthood (Howlin, Mawhood, & Rutter, 2000). The proposed intervention has the potential to provide evidence-based guidance for clinicians and families to support critical early language and communication development for these children, minimizing the negative impacts of early language impairments on long-term outcomes.

Chapter 2

Methods

Research design

The study used a single case, multiple-probe across participants design (Horner et al., 2005; Kratochwill et al., 2010). Single case designs are effective tools for initial intervention studies, as they allow for tracking of learning over time. Additionally, each participant serves as their own control (Kratochwill et al., 2010), which is advantageous for heterogeneous populations, such as children on the autism spectrum. The study included three phases: baseline, intervention, and maintenance. Participants were grouped into two legs of data collection with three participants in each leg, for a total of six participants. This design allowed for the potential for three demonstrations of the treatment effect in the first leg while controlling for threats to internal validity, as well as a replication in the second leg. The first three consented participants who met the inclusion criteria comprised the first leg of the study and began baseline concurrently. Intervention for the first leg was staggered across participants, to establish experimental control (Kratochwill et al., 2010). All participants in the first leg completed a minimum of five baseline sessions (Kratochwill et al., 2010). The second and third participant in this leg remained in baseline until the previous participant demonstrated an intervention effect, operationalized as two consecutive sessions in intervention with performance on the primary dependent variable (total number of symbolic turns in 10 minutes) above the highest baseline point.

The final three consented participants who met the inclusion criteria were assigned to the second leg of the study, which was completed nonconcurrently, as a result of recruitment delays. Nonconcurrent multiple baseline designs differ from concurrent designs in that baseline session numbers are predetermined for varying lengths and randomly assigned to participants as they are consented (Watson & Workman, 1981). Additionally, participants begin study procedures as they become available, and session phases may or may not overlap across participants in the same study leg (Watson & Workman, 1981). Similar to conconcurrent methods, nonconconcurrent multiple baseline designs control for history and include multiple demonstrations of effect to provide methodological rigor (Watson & Workman, 1981). Nonconcurrent designs may also be more practical in many applied research settings, allowing participants to begin study procedures as soon as they are recruited (Watson & Workman, 1981). All participants in the second leg of the current study had some degree of overlapping study phases (see Figure **3-2**). The number of sessions in each baseline phase was staggered across participants within the second leg, preset and randomly assigned at five, seven, and nine sessions, respectively. Each of these three participants transitioned into intervention once they had completed their predetermined baseline session number, given relative stability of performance on the primary dependent variable, but without reference to the performance of the other two participants in that leg. Five of the six study participants attended different schools and/or clinical therapy programs, resided in different towns, and participated in independent locations, reducing the probability that any similar effects of history might have impacted the performance of multiple participants. Two participants (Owen and Ian) attended the same applied behavioral analysis (ABA) therapy program, though for afternoon and morning sessions, respectively.

Participants and setting

Inclusion criteria and assessment of participant characteristics

Approval for the study was obtained from the university Institutional Review Board prior to study initiation (see Appendix A). Participants were recruited through local early intervention providers, schools, and therapy centers that served children on the autism spectrum.

Inclusion criteria included: (a) age 2-5; (b) diagnosis of autism; (c) in the First Words stage of expressive language development (as defined by Tager-Flusberg et al., 2009); (d) functional vision, hearing, and motor skills to interact with storybooks on a direct selection touch screen tablet; and (e) exposure to English at home. Exclusion criteria included previous proficiency with the AAC app to be used in the study (GoVisual). All inclusion and exclusion criteria were assessed after informed consent had been obtained.

The presence of autism characteristics sufficient for diagnosis was corroborated using the Childhood Autism Rating Scale – 2nd Edition (CARS-2; Schopler et al., 2010). Information for the CARS-2 included input from caregiver interviews as well as observation of participants over multiple sessions. Validation of the participant's language stage was assessed via multiple measures, in order to accurately represent current language skills (Tager-Flusberg et al., 2009). Children in the First Words stage generally use between 2-15 spoken words (and generally less than 30), are not yet combining words, use a variety of different speech sounds but may only use CV or CVC word structure, and communicate for at least two different functions (e.g., request, comment; Tager-Flusberg et al., 2009). Measures used to assess language stage included: (a) a 20-minute natural language sample gathered during interaction with a caregiver; (b) the MacArthur-Bates Communication Development Inventory – 2nd Edition (MCDI), a caregiver-report measure of expressive language appropriate for children in the First Words stage of development (Fenson et al., 2007); and (c) caregiver interview. Caregiver report measures, paired with direct caregiver interview, can provide information about child language that may not be captured during natural language samples (e.g., language or language functions not relevant to that particular context, or idiosyncratic language knowledge; Tager-Flusberg et al., 2009). Information on vision, hearing, motor skills, and English exposure were collected via caregiver report and observation.

Natural language samples included two activities: (1) a typical interactive context (e.g., play, snack) and (2) shared reading using the storybooks selected for the study within the GoVisual app (without hotspots present). All participants were reported to be interested in books and frequently engaged in shared reading with their caregivers, so this activity represented a familiar, naturalistic context, albeit within a novel storybook format (digital books in the GoVisual app). Including shared storybook reading using the study materials as part of the natural language sample also provided a pre-baseline measurement for participant communication during shared reading with a familiar partner. Thus, any communication gains during baseline had a point of comparison to participants' typical communication with a familiar partner in an equivalent activity.

Table **2-1**: Participant demographics.

Participant	Age/gender/ race[1]	CARS-2 assessment	Study location	Communication modes at baseline	MCDI	NLS[2] turns	Services
Henry	5;5/M/white	Severe autism	Home (kitchen table)	Speech: 5-10 single words/word approximations Gestures: e.g., points to request objects, waves hello/goodbye High tech dynamic display grid-based AAC system (TD Snap on an iPad), including a small number of added personalized vocabulary concepts	178	0	ABA, OT, SLP
Lila	3;1/F/white	Moderate autism	Preschool (familiar classroom or meeting room)	Speech: 20-30 single words/word approximations Gestures: e.g., points to request objects, waves hello/goodbye, shakes head for yes/no, “shhh” gesture Sign language: knows and uses over 50 signs – often needs initial prompting High tech dynamic display grid-based AAC system (TouchChat on an iPad) – available mostly in 1:1 speech sessions at school	374	2	SLP
Lucas	5;11/M/white	Severe autism	Grandparent’s home (playroom)	Speech: vocalizes, no consistent spoken words/word approximations Gestures: e.g., initiates high five for “goodbye,” reaches toward requested objects, “shhh” gesture High tech dynamic display grid-based AAC system (TouchChat on an iPad), including a small number of added personalized vocabulary concepts	134	0	OT, SLP
Owen	4;3/M/white	Severe autism	ABA therapy center (familiar classroom)	Speech: 10-20 single words/word approximations or rote phrases (e.g., “I did it,” “I done”) Gestures: e.g., touches preferred object and looks toward communication partner, pushes away nonpreferred items	–	0	ABA, OT
Teagan	4;7/F/white	Severe autism	Preschool (familiar meeting room or classroom)	Speech: 5-10 single words/word approximations (e.g., “ball,” “thank you,” “all done”) Gestures: e.g., points to request objects Low tech AAC board with digital photographs of preferred foods/objects (only at home – approximately 30 concepts total, 5-10 available at a time)	232	0	ABA, OT, PT, SLP
Ian	3;0/M/white	Severe autism	ABA therapy center (familiar playhouse) and home (playroom)	Speech: 10-12 single words/word approximations (e.g., “yeah,” “no,” “cookie,” “ball”) Gestures: points to request objects, head shake and nod for yes/no High tech dynamic display grid-based AAC system (GoTalk Now on an iPad with personalized programming and digital photographs)	131	1	ABA, OT, PT, SLP

Note: CARS-2: *Childhood Autism Rating Scale-2nd Edition* (Schopler et al., 2010); MCDI: *MacArthur-Bates Communicative Development Inventories – Words and Gestures* (Fenson et al., 2007) raw receptive vocabulary count; NLS: natural language sample; AAC: augmentative and alternative communication; TD: Tobii Dynavox; ABA: applied behavior analysis; OT: occupational therapy; SLP: speech language pathology services; PT: physical therapy

[1] All participants were identified by their caregivers as non-Hispanic.

[2] Number of symbolic communicative turns taken by the participant during the shared storybook reading portion of the natural language sample with their participating caregiver, completed as part of the screening process

All participants were 2-5 years old with a diagnosis of autism, per caregiver report, and met criteria for diagnosis on the CARS-2 (see Table **2-1** for participant demographics). Five out of six participants fell in the range of severe autism characteristics, with one participant in the moderate range. All participants were in the First Words stage of expressive language development based on results from the accumulated language measures. Participants were all reported by their caregivers to have functional vision, hearing, and motor skills to interact with a touchscreen tablet, and were exposed to English at home. Four out of six participants had access to tablet-based high tech AAC systems (see Table **2-1**), but no participants were familiar with the AAC app used in the study (GoVisual). During shared storybook reading with their caregivers as a part of the natural language sample, four out of six participants took no symbolic turns using any communication modality. Two participants (Lila and Ian) took a limited number of symbolic communicative turns during shared storybook reading with their caregivers. Lila took two turns, using the signs for "more" and "roll" after a model from her mother. Ian took one symbolic turn, using a speech approximation for "cookie."

Setting and context

The study procedures took place in a familiar location convenient for participants and their families, and included parents' home, grandparents' home, preschool, and applied behavior analysis (ABA) therapy settings. Sessions were one-on-one with the researcher, a certified speech language pathologist, during a shared interactive storybook reading activity in a quiet space at the location of participation (e.g., classroom, playroom at home). Conducting the study in a familiar context and within a naturalistic routine increased the ecological validity of study procedures and results, better reflecting the actual language development and communication behaviors of children within their natural environments, and potentially leading to greater generalization of communication skills outside of the intervention context.

Participants

Henry

Henry was 5 years, 5 months old when the study began. He had a diagnosis of autism, confirmed through administration of the CARS-2, with his raw score falling in the range of severe autism. Henry was reported by his mother to have functional vision, hearing, and motor skills, and was observed to be very adept at accessing and navigating touchscreen technology (e.g., tablet, phone, his own high tech AAC system). His mother shared that Henry enjoyed interacting with books but would generally flip to and stay on a certain page, and often preferred to look at books independently.

Henry had access to a grid-based dynamic display AAC system that he had been using for several years (TD Snap on an iPad with Core First vocabulary). His AAC system had a grid size of 20 and used Picture Communication Symbols to represent concepts, with some additional digital photographs and personalized programming. In total, Henry's aided AAC system contained approximately 2,700 concepts, the majority of which were part of the pre-set vocabulary set. Henry used approximately 50 concepts within his aided AAC system expressively, most of which were personalized vocabulary concepts added into the system. He mostly used his aided AAC system to independently request preferred foods or activities with single words, or to request to use the bathroom, as potty training was an active goal at the time of the study. Henry also communicated about 5-10 single spoken words or word approximations, similarly to request preferred foods or activities. He used some conventional gestures (e.g., waving for hello/goodbye), and pointed to request. Henry was reported to understand 178 different concepts on the MCDI and a number of familiar phrases (e.g., "Go get ___," "Sit down," "Let's go").

Henry lived at home with his mother and father. He attended a half-day ABA clinical program five days a week, with additional home-based ABA therapy in the mornings two days a week. About half of each day at the ABA clinic Henry was one-on-one with a behavior therapist, with the other part of the day spent in group activities and free play with about 10 other children. He also received speech-language pathology services and occupational therapy services at the ABA program once a week. Henry participated in the study at his home at the kitchen table, which was a familiar location for activities with his in-home ABA therapist.

Lila

Lila was three years, one month old when the study began. She had a recent diagnosis of autism, confirmed through administration of the CARS-2, with her raw score falling in the range of moderate autism. Lila was reported by her mother to have functional vision and motor skills and was observed to engage in a pretend play cooking activity with ease. Lila's mother noted that her current hearing appeared to be unimpaired, but that Lila had a history of otitis media in her ears that substantially affected her hearing in the past. Tubes had been placed to mitigate her otitis media about three months prior to study participation, with no indication of continued hearing impairment. However, it was unclear how long Lila's hearing had been affected. As hearing impairments in young children can be misinterpreted as early signs of autism, it is important to note that Lila continued to displayed characteristics associated with autism over the course of the study. Lila's mother indicated that she enjoyed reading books with her familiar communication partners.

Lila communicated predominantly though gestures, manual signs (approximately 50), and about 20-30 single spoken words or word approximations. According to parent report, she learned new signs after 1-2 models, both from communication partners or from watching preferred YouTube videos of songs with incorporated signs. Lila used both speech and signs to communicate for a variety of functions, including to request, answer simple WH preference questions (e.g., "what color crayon do you want?"), to indicate she was finished, and in the context of song routines. At study initiation, Lila was infrequently observed to use her sign or spoken word lexicon spontaneously, and often required spoken and/or gestural prompting. Lila also babbled or used jargon, though this was generally not directed towards communication partners. She pointed to request and would also lead her communication partner to what she wanted. Lila's mother reported that she could understand "a lot more" than she could communicate expressively. Lila was reported to understand 374 concepts on the MCDI and several familiar phrases (e.g., “Sit down,” “Give me a hug,” “Give it to mommy”).

Lila’s mother reported that Lila briefly had access to a high tech grid-based AAC app on an iPad (GoTalk Now) with personalized programming and digital photographs for a few months right before beginning the study. However, Lila lost access to this system during the transition out of early intervention speech services at three years of age. Partway through participation in the study, Lila was provided a different high tech, grid-based AAC app with a large, preprogrammed vocabulary set that represented vocabulary using Symbolstix picture symbols (TouchChat on an iPad) through her school-based speech-language pathology services. Her new AAC system was available to her during 1:1 sessions with her school speech-language pathologist, and occasionally throughout the school day. The system did transition to home, though Lila’s mother reported that it was not used at home.

Lila lived at home with her mother, father, elementary-age brother, and infant sister. She attended an inclusive full-day preschool program five days a week in a class of approximately eight students, one teacher, and two paraprofessionals. Lila also received speech-language pathology services at school. She participated in the study at her preschool, in an empty classroom or meeting room, depending upon the space available that day. Lila’s performance did not appear to be impacted by the two different participation locations, which varied randomly over both baseline and intervention.

Lucas

Lucas was 5 years, 11 months old when the study began. He had a diagnosis of autism, confirmed through administration of the CARS-2, with his raw score falling in the range of severe autism. Lucas’s grandmother reported that he had functional vision, hearing, and motor skills. He was also observed to navigate touchscreen technology independently (e.g., tablet, phone, his own high tech AAC system). Lucas’s grandmother shared that he enjoyed reading books with his familiar communication partners.

Lucas had been using a grid-based dynamic display AAC system for the last several years (TouchChat with WordPower on an iPad). His AAC system had a grid size of 20 and used Symbolstix picture symbols to represent vocabulary, with some digital photographs and personalized programming. Lucas's aided AAC system contained a pre-set vocabulary of thousands of concepts, approximately 55 of which he used expressively. Lucas predominantly used his AAC system to request preferred foods or songs with single words. Occasionally, he would use built-in phrase support to request preferred foods (i.e., the app would automatically navigate through page sets to support simple sentence formation, such as I WANT + TO EAT + PANCAKES), though he generally required verbal prompting. He had a special interest in the calendar and birthdays and would accurately use his AAC system to communicate the birth month of familiar people or the current date. Lucas also used a small number of conventional gestures (e.g., the "shhh" gesture) as well as more idiosyncratic gestures (e.g., initiating a high five for "goodbye") to communicate, as well as reaching toward requested objects. Lucas was reported to understand 134 different concepts on the MCDI and a variety of familiar phrases (e.g., "Get up," "Give me a hug," "Take off your backpack").

Lucas lived at home with his mother, father, and middle school-aged older sister. Lucas and his sister also spent a significant amount of time at their grandparents' house (after school each day and during the day on weekdays in the summer). Lucas attended a full-day kindergarten autistic support classroom five days a week in a class size of approximately 10 students. He received speech-language pathology and occupational therapy services once a week from both his school and at an outside clinical therapy group. Lucas participated in the study at his grandparents' home, in a separate playroom.

Owen

Owen was 4 years, 3 months old when the study began. He had a diagnosis of autism, which was confirmed through administration of the CARS-2. Owen's raw score on the CARS-2 fell in the range of severe autism. Owen's mother reported that he had functional vision, hearing, and motor skills, but that he did not yet consistently isolate a point as either a proximal or distal gesture. However, his mother and ABA therapist indicated that he was able to select on a touchscreen, with some effort. The researcher did not note significant difficulty with fine motor skills when Owen was observed playing with a variety of small toys during the prescreening session. However, he did not attempt to touch the tablet screen during the prescreening process, and thus this specific motor behavior was not observed. Owen's mother noted that he was very interested in storybooks, but it was a challenge to maintain his attention for an entire book. Additionally, his mother noted that he was generally more comfortable with and interested in physical books than tablets/phones. During the natural language sample prior to beginning the baseline phase, Owen did sit and attend to the sample digital book with his mother.

Owen used between 10 and 20 single spoken words or rote phrases to communicate (e.g., "I did it," "No no no," "I done"), mostly to request preferred people or items, or termination of an activity. He would generally lead his communication partner to what he wanted and put their hand on something to request and push away nonpreferred items. Occasionally, Owen would touch the lock on the door at home and look at his parents to request to go outside. The researcher was unable to obtain a completed MCDI from Owen's family.

Owen lived at home with his mother and father. He attended a half day ABA clinical program three days a week. About a third of his time at the ABA program each day consisted of one-on-one direct instruction with a behavior therapist, one third in small group activities with peers (e.g., trampoline), and a third in free play with about 10 other children. Owen participated in the study at the ABA therapy center, in a familiar classroom.

Teagan

Teagan was 4 years, 7 months old when the study began. She had a diagnosis of autism, which was confirmed through administration of the CARS-2. Her raw score was in the range of severe autism. Teagan was reported by her parents to have functional vision, hearing, and motor skills, with advanced fine motor dexterity. Teagan was observed accessing and navigating touchscreen technology adroitly (i.e., tablet). Teagan's parents shared that she enjoyed reading books with her familiar partners.

Teagan used between 5-10 single spoken words or word approximations to communicate (e.g., "ball," "all done"), mostly to request preferred foods or objects. Teagan's parents reported that she would mimic the vocal intonation of short phrases (e.g., “thank you,” “I love you”) in familiar contexts reliably but did not make recognizable speech approximations of the words. At the time of the study, Teagan’s ABA therapist had recently introduced a low-tech communication board with an “I want ____” line and digital photographs of preferred foods and objects for use at home. Teagan’s parents would rotate through a variety of items on the board each day, and Teagan would independently move a desired item to the “I want ____” line to request. She would also point to specific objects to request. Teagan’s parents reported that she understood 232 different concepts on the MCDI, along with a number of familiar phrases (“Mommy’s home,” “Give me a kiss,” “Look here”).

Teagan lived at home with her mother, father, and infant younger brother. She attended a full-day kindergarten autistic support classroom four days a week with a class size of approximately five children, with one teacher and one paraprofessional. She received speech-language pathology, occupational therapy, and physical therapy services at school once a week. Teagan also received ABA therapy at home two days a week, and at school once every other week. Teagan participated in the study at school, in a familiar empty meeting room.

Ian

Ian was 3 years, 0 months old when he began study participation. He had a diagnosis of autism, confirmed through administration of the CARS-2, with a raw score in the severe range of autism. Ian was reported by his mother to have functional vision, hearing, and motor skills, with slightly delayed gross motor skills and some balance challenges. Ian was observed skillfully accessing and navigating his grid-based AAC system on a touchscreen tablet. Ian’s mother indicated that shared storybook reading was a preferred activity.

Ian used between 10-12 single spoken words or word approximations to communicate (e.g., “yeah,” “no,” “cookie,” “ball”), mostly to request preferred foods, objects, or people, but also to confirm (“yeah”) and protest (“no”). Ian’s mother reported that many of his word approximations sounded very similar, but that Ian would reliably confirm the intended meaning by answering yes or no. Ian had recently begun to point to request and use a head shake or nod for yes/no. Ian also had access to a personalized, grid-based dynamic display AAC system (GoTalk Now on an iPad). His AAC system had a grid size of 4-12 symbols and used digital photographs to represent vocabulary. In total, Ian's aided AAC system contained approximately 100 personalized, preprogrammed concepts, 5-10 of which he used expressively. As with speech, Ian predominantly used his AAC system to request preferred foods, objects, or people using single words. Ian's mother shared that he seemed to understand significantly more than he could communicate. He was reported to understand 131 different concepts on the MCDI and a number of familiar phrases ("Sit down," "Give it to mommy," "Let's go").

Ian lived at home with his mother, father, and two school-age older siblings (elementary-age brother and middle school-age sister). He attended a half-day ABA clinical therapy program three mornings a week. His time at the ABA program was divided equally between one-on-one direct instruction with a behavior therapist, small group activities with peers, and free play with about 10 other children. Ian received speech-language pathology and occupational therapy services once a week, and physical therapy two times per month. Ian participated in the study both at the ABA therapy center in a familiar playhouse, as well as at home in the playroom. Ian's performance did not appear to be impacted by the two different participation locations, which each had consistent representation over both baseline and intervention.

Materials

Study materials consisted of the storybooks used in both baseline and intervention, and the VSD AAC app (GoVisual).

Storybooks

Each participant had access to an individualized set of five storybooks across all study phases (baseline, intervention, and maintenance), drawn from a list of 10 potential books. In order to support engagement and increase ecological validity, caregivers and participating children were consulted in both determining the initial pool of 10 storybooks as well as the five books within their set. Each set of five books was unique to each participant, though there was overlap of books across participants.

The initial list of 10 storybooks included titles from the Pete the Cat, Sesame Street, and Daniel Tiger series. To maintain a level of consistency across storybooks and ensure they were developmentally appropriate, criteria from Caron et al. (2016) were applied to selected storybooks for the initial pool. All books: (a) included 1-2 simple sentences on each page; (b) included engaging and concrete illustrations; (c) represented language and storylines that were appropriate for young beginning communicators; and (d) had 12 pages (Caron et al., 2016). The text and page length of storybooks was adapted to meet these criteria, as necessary.

Each book had five associated signs or gestures that were performed by the researcher during the shared storybook reading activity on specific pages across all study phases (see Appendix C). Incorporating specific signs/gestures related to an activity is not uncommon in NDBI procedures, with the goal of creating a context for socially-contingent imitation (e.g., Engelstad et al., 2020; Feuerstein & Landa, 2020). Many NDBIs focus on reciprocal imitation across domains (e.g., language, play, social engagement), including the communication partner imitating the child's motor movements, play schemas, and speech approximations. Communication partners also typically infuse intentional targets for child imitation, including (but not limited to) motor movements, play schemas, and speech approximations. In the context of the current study, these signs/gestures also served as a form of modeled unaided AAC that was available to participants in both baseline and intervention.

Book-related signs/gestures were predominantly drawn from the American Sign Language sign for each associated vocabulary concept (Lifeprint, n.d.). A small subset of signs/gestures were adapted to fit the exact context of how those concepts appeared in the storybook and/or to require less dexterity (e.g., ding-dong, turn off, build, walk, ride). All vocabulary selected to have an accompanying sign/gesture: (1) appeared in the text of the book, (2) represented an action word (e.g., walk, sleep) or sound effect (e.g., ouch, whee), and (3) was represented visually in the illustration of that book page (e.g., "bite" – Cookie

Monster is about to take a bite of cake in the illustration on the associated storybook page). Each storybook had five different associated sign/gestures. However, four of the book-related signs/gestures were targeted in two separate books (see Appendix C). Thus, participants may have had exposure to 21-25 different signs/gestures, depending on their particular set of five books.

Book-related signs/gestures provided consistent opportunities for embodied learning (Englestad et al., 2020) of relevant action concepts across both baseline and intervention. By imitating these gestures and actions, children had the opportunity to engage in hands-on, experiential learning of those concepts, paired with language input (e.g., child imitates the researcher pretending to walk, in conjunction with hearing the language label of "walk" and seeing the illustration of Pete the Cat walking to the bus stop on the storybook page). As a result, these embodied sign/gestures may have aided in comprehension of the underlying concept and/or the connection between the spoken word and the underlying concept. Additionally, the inclusion of book-related signs/gestures allowed for modeling of unaided communication across all study phases. Early gestures and imitation are often included as targets within NDBI interventions (Schreibman et al., 2015), and thus these book-specific signs/gestures were a part of NDBI procedures in both baseline and intervention.

VSD AAC app

Across all study phases, participants had access to the same VSD AAC app (GoVisual app on an Apple iPad). However, during baseline, no communication supports were available within the app; it was simply used as a platform to present the books in digital format. In intervention, GoVisual was used as intended, as a VSD-based AAC app that supports just-in-time programming of language concepts within a visual scene with digitized speech output. Digital photographs can be added to the app as VSDs by using the onboard tablet camera or downloading a picture from the internet or another device (e.g., sharing photos from a smart phone). AAC "hotspots" can be added by drawing on the screen to circle target language concept within a visual scene, then recording digitized speech of the language target (e.g., circling cookies in the scene, then recording digitized natural speech of "cookies;" see Figure **2-1**).

Touching the hotspot then triggers speech output of the associated recorded speech. Hotspots were translucent yellow and were set to remain visible, superimposed on top of the visual scene. They could be any shape, maintaining the outline of how they were originally drawn. Hotspots were present within the app during intervention and maintenance (see Figure **2-2**). No hotspots were available during baseline (see Figure **2-2**); the app was simply used to read the storybooks within a digital format.

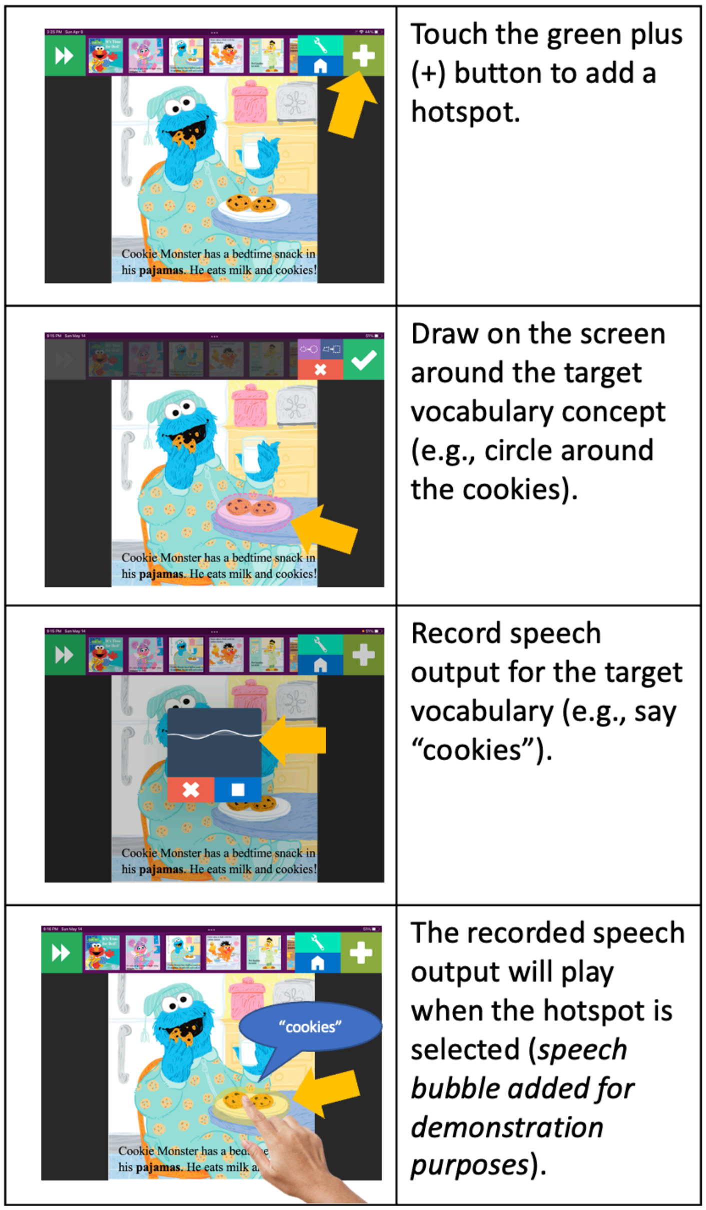

Figure **2-1**: Programming hotspot vocabulary within a VSD in GoVisual.

Figure **2-2**: Participant home page (left), storybook page during baseline (no hotspots – middle), and VSD storybook page during intervention (including hotspots – right).

Each participant's set of five storybooks was added to the VSD app, creating individualized sets of digital books. Each participant had their own home page within the VSD app, which included a picture of the front cover of each of their five storybooks and the title of each book in a vertical list (see Figure **2-2**). Participants could select a book to read by touching the cover/title, and that book would then open to the front cover. The other pages of the selected book were represented as miniature icons in a horizontal menu above the current page, and any page could be opened by touching it from the menu (see Figure **2-2**). Participants could also scroll through all pages in the book by swiping right and left in the horizontal page menu. A home button was also visible, which enabled participants to return to their home page and select a different book.

Participants only had access to their five digital books in the VSD app during shared storybook reading. No physical books were available during any study phase. From a perspective of methodological rigor, by only having the storybooks available as digital books within the VSD app, the shared context for interaction could naturally be held constant across study phases that did and did not include aided AAC supports. This allowed the focus of intervention to specifically target introduction of aided AAC (i.e., hotspots within the VSDs), just-in-time programming, and aided AAC input, eliminating the potential confounds of introducing digital books within the AAC app on the tablet itself during intervention.

Prior to the first intervention session, one hotspot was added to each book page within the app. This allowed the researcher to both provide at least some aided AAC input during intervention sessions and also ensured that participants were aware of this new hotspot feature within the digital storybooks. Each storybook contained 12 total hotspots (one per page), and 5-9 unique concepts. More than one hotspot within a book (or across books) could be programmed with the same concept. Preprogrammed vocabulary added as hotspots consisted of single nouns, verbs, or interjections, reflecting the First Words developmental stage of participants. Each preprogrammed hotspot was (1) included in the book text on that page (to allow for aided AAC input) and (2) imageable within the illustration. Priority was also given to concepts that met the above criteria and overlapped with book-related signs/gestures and/or vocabulary targeted within the main comprehension measure of spoken words. As a result, storybook hotspots generally overlapped with 2-4 associated signs/gestures for that book. The intention of this overlap was to increase participants' exposure to the vocabulary targeted in the main comprehension measure of spoken language, across a variety of instances and modalities. Hotspots were drawn to encompass the targeted vocabulary concept within the illustration on that book page and be large enough to direct select, but also allow room for additional hotspots to be added later, in response to participant interest. See Appendix D for a list of all preprogrammed vocabulary and screenshots of the hotspots on the book page.

Procedures

Baseline

Baseline sessions occurred 2-4 times per week for approximately 15 minutes each. The baseline phase established participants' symbolic communication within the context of an NDBI – and also allowed investigation of any communication or language growth with the introduction of NDBI procedures alone – before incorporating the VSD AAC intervention with just-in-time programming. During each baseline session, the researcher and participant engaged in a shared reading activity with the participant's set of five digital books within the GoVisual app on the iPad. Participants had access to all five of their books in every session and were able to choose to read multiple books per session. All participants read a minimum of two books per session and were able to navigate to a new book at any time (e.g., partway through reading a book). Participants were also able to select specific pages within a book. No hotspots were available within the storybooks during baseline (neither preprogrammed nor added just-in-time). If participants had their own aided AAC system, it was available wherever it would typically be in the environment, and participants were permitted to access their AAC system as they typically would. Only one participant (Henry) used his personal AAC system to communicate during study sessions, and he did so only on rare occasions to request a snack or request to use the bathroom.

Baseline sessions incorporated the following NDBI strategies during shared reading with the participant: (a) setting up an interactive context; (b) following the child's lead while supporting balanced turn taking by systematically presenting communication opportunities followed by an expectant delay, and a contingent response; (c) least-to-most prompting; (d) modeling language; (e) expanding on child communication; and (f) providing natural and child-contingent reinforcement (Schreibman et al., 2015; see "NDBI strategy use at baseline" in Table **2-2** for specific strategy descriptions).

Table **2-2**: NDBI strategies in baseline and intervention.

NDBI strategy	NDBI strategy use at baseline	Integration of VSD AAC and NDBI strategies during intervention
Set up an interactive context	Remove distractors in the environment; ensure digital storybook is accessible to child	Remove distractors in the environment; ensure storybook with embedded hotspots is accessible to child
Follow the child's lead while supporting balanced turns	Respond to child's interests during the activity; take turns during the activity	Respond to child's interests during the activity; program vocabulary hotspots into storybook in response to child's observed interests; use the AAC hotspots to take turns in the activity
Use least-to-most prompting	Provide increasingly more supportive prompts to encourage the child to engage (e.g., expectant delay → gestural prompt → spoken prompt, as required)	Provide least-to-most prompting to encourage child to engage in activity and use AAC hotspots for expression
Model language	Use spoken language relevant to the activity; draw the child's attention to relevant actions, objects, people, etc.	Provide spoken language relevant to the activity and also use the AAC hotspots to model language (i.e., aided AAC input) and draw child's attention to relevant people, actions, and objects
Expand on child communication	Restate child utterances in a slightly longer spoken phrase (e.g., child: "Car!"; researcher: "Drive the car!")	Expand child utterances using slightly longer spoken phrases and aided AAC input
Use natural and child-contingent reinforcement	Reinforce the child in ways that align with the interaction (e.g., the child turns to look at the researcher at a particular point in the storybook → the researcher repeats that word or phrase and expands)	Reinforce the child in ways that align with the interaction (e.g., the child turns to look at the researcher at a particular point in the storybook → the researcher repeats that word or phrase and expands)

At the beginning of every baseline session, the researcher removed distractors from the environment and ensured that the iPad with the digital storybooks was positioned in front of the participant. The researcher followed the child's lead by allowing the participant to choose what storybook(s) to read, as well as navigate through the book pages (including navigating directly to preferred pages). The researcher supported balanced turn taking by taking a turn on each storybook page, but also offering an expectant delay for the participant to also take a turn on each page. Additionally, the researcher used least-to-most prompting to encourage the participant to take a communicative turn on each page if they did not do so spontaneously. Following a communication opportunity (i.e., researcher comment or simple WH question), least-to-most prompting consisted of an expectant delay (i.e., looking at the participant with an animated facial expression for three seconds), gestural prompt (i.e., pointing towards the storybook generally), and then spoken prompt (i.e., repeating the comment or answering the question). The researcher modeled spoken language throughout the storybook reading activity through relevant comments and questions, spoken prompts during least-to-most prompting, and expansions on participant communication. The researcher expanded on all child communication by repeating participant communication (or communication attempts) in a slightly longer utterance (e.g., child: "Cookie Monster!"; researcher: "Cookie Monster mixes!"). All reinforcement was natural and child-contingent across study sessions, in that the researcher only provided the socially expected natural response to child communication attempts and behavior (e.g., if the participant navigated to a preferred page, the researcher read that page).

These NDBI strategies were integrated into a procedural sequence that repeated on each book page (see Figure **2-3**). During the baseline sessions, the researcher read through each book selected by the participant sequentially, unless the participant navigated independently to a specific page. On each book page, the researcher read the book text, provided a communication opportunity (i.e., asked a simple WH question or made a comment – e.g., "What is Cookie Monster doing?"), and encouraged the participant to communicate using least-to-most prompting (i.e., expectant delay, gestural prompt, spoken prompt; see Table **2-2**). If the participant made a communication attempt at any point during the shared reading activity, the researcher responded contingently by mapping spoken language onto the participant's communication attempt and then expanding on the participant's communication. For example, if the participant touched a character on the storybook page, the researcher labeled the vocabulary item (e.g., "Cookie Monster!") and expanded (e.g., "Cookie Monster mixes!"). If participants made a communication attempt prior to the researcher providing a communication opportunity, an additional communication opportunity was not provided on that page.

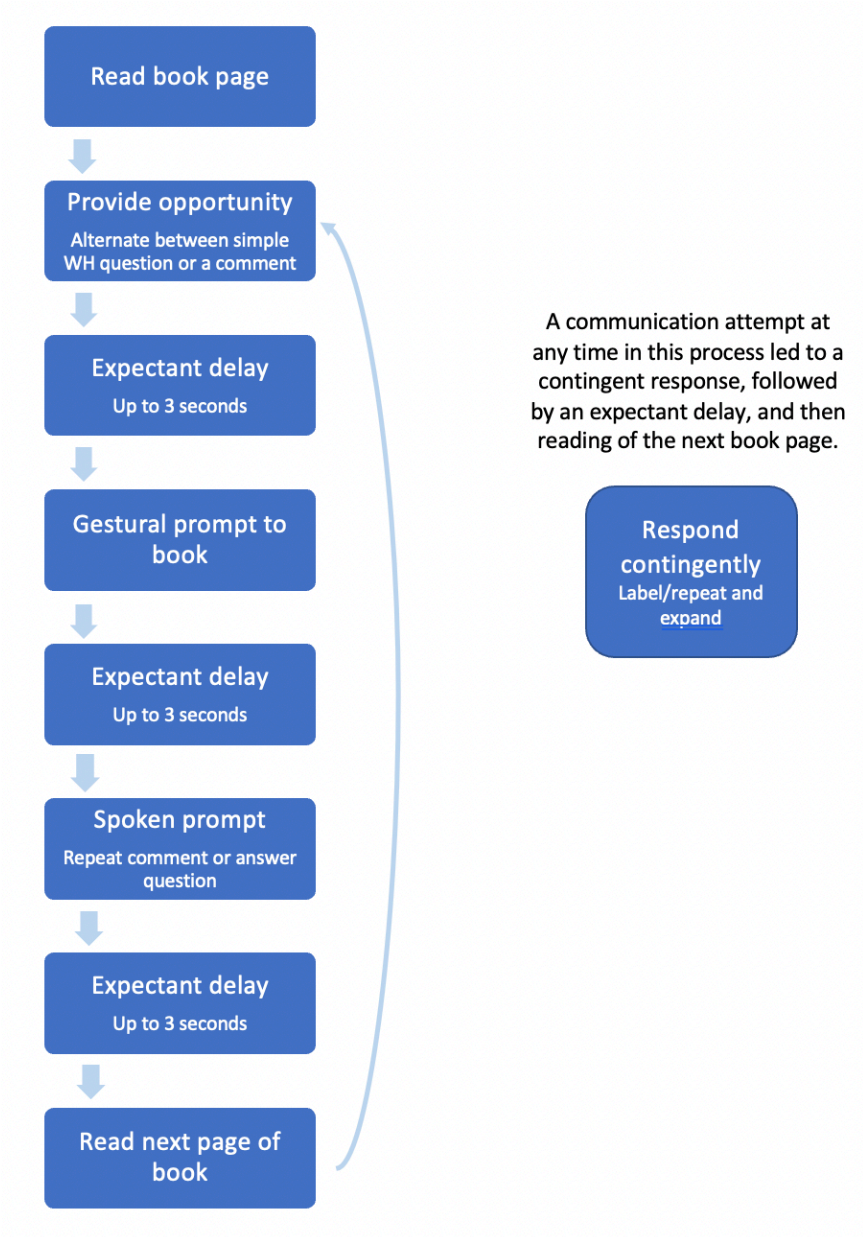

Figure **2-3**: Baseline procedural sequence.

The researcher responded to both symbolic and nonsymbolic communication as a communication attempt by the participant. A communication attempt was defined as the participant pointing at or focusing attention specifically on something in the book or specific to the activity (e.g., pointing to researcher's feet or own feet after researcher just pretended to walk), gesturing, doing/attempting a related book action (e.g., the participant pretending to walk), saying a spoken word or word approximation, using a sign or sign approximation, or selecting a related concept in their personal grid-based AAC system. Thus, communication attempts included all book-related symbolic communication, but all book-related communication attempts were not necessarily symbolic (and did not all count towards the main dependent variable, number of symbolic communicative turns). The primary dependent variable of the study (number of symbolic communicative turns per 10-minute session) *only* included recognizable symbolic communication by the participant. However, nonsymbolic communication (e.g., pointing at the book or the researcher) or unclear communication (e.g., an unintelligible speech approximation) was considered a communication attempt, and was responded to contingently by the researcher, in order to shape participant communication.

Each participant remained in the baseline phase for a minimum of five sessions. Participants in the first, concurrent leg of the study continued in baseline until a stable baseline (i.e., fluctuation around the mean of 3 or less turns for three consecutive sessions) or descending trend was established for the main dependent variable (total number of symbolic turns in 10 minutes). The second and third participant in the first leg of the study also remained in baseline until the previous participant demonstrated an intervention effect, operationalized as two consecutive sessions in intervention with performance above the highest baseline point on the main dependent variable. Participants in the second, nonconcurrent leg of the study started baseline at different points in time. Each participant in this leg had a preset, randomly assigned baseline phase length of five, seven, or nine sessions, respectively. Each of these three participants transitioned into intervention once they had completed their predetermined baseline session number, regardless of their stability of performance on the main dependent variable, or the performance of the other two participants in that leg.

Intervention

Intervention sessions also occurred 2-4 times a week for approximately 15 minutes each. The number of baseline and intervention sessions each week remained consistent across phases for each participant. Intervention procedures were designed to incorporate VSD AAC technology into the NDBI strategies within the same interactive storybook reading context (see Table **2-2**). All NDBI procedures and digital storybooks available in baseline were also present during intervention. The procedural sequence on each page also remained consistent, with the exception that AAC hotspots were now included within the digital books, the researcher provided aided AAC input using the hotspots within the books, and the researcher also programmed additional hotspots just-in-time in response to participant interest (see Figure **2-4**). Thus, the independent variable in this study encompassed the inclusion of preprogrammed embedded hotspots with digitized speech output within the same set of digital books, just-in-time programming of new hotspots in response to participant interest, and aided AAC input.

One preprogrammed hotspot was drawn freehand on the storybook page within GoVisual, for a total of twelve individual preprogrammed hotspots within each book (though the concepts within and across books overlap slightly – see Appendix D). Preprogrammed vocabulary added as hotspots consisted of single nouns, verbs, or interjections. Each preprogrammed hotspot was (1) included in the book text on that page (to allow for aided AAC input) and (2) imageable within the illustration. Priority was also given to concepts that met the above criteria and overlapped with book-related signs/gestures and/or vocabulary targeted within the main comprehension measure of spoken words. Hotspots were typically 1-2 inches in size but varied based upon the size of the target concept within the page. Digitized speech output was recorded during hotspot preprogramming by the researcher and consisted of the single spoken word.

Just-in-time programming occurred in response to a participant's communication attempt. When the researcher observed the participant pointing at or focusing attention specifically on something in the book or specific to the activity, gesturing, doing/attempting a related book action, saying a spoken word or word approximation, using a sign or sign approximation, or selecting a related concept in their personal grid-based AAC system, the researcher labeled the attempt via speech (e.g., "Elmo!"), then initiated the process of programming a hotspot on that page representing the concept of interest.

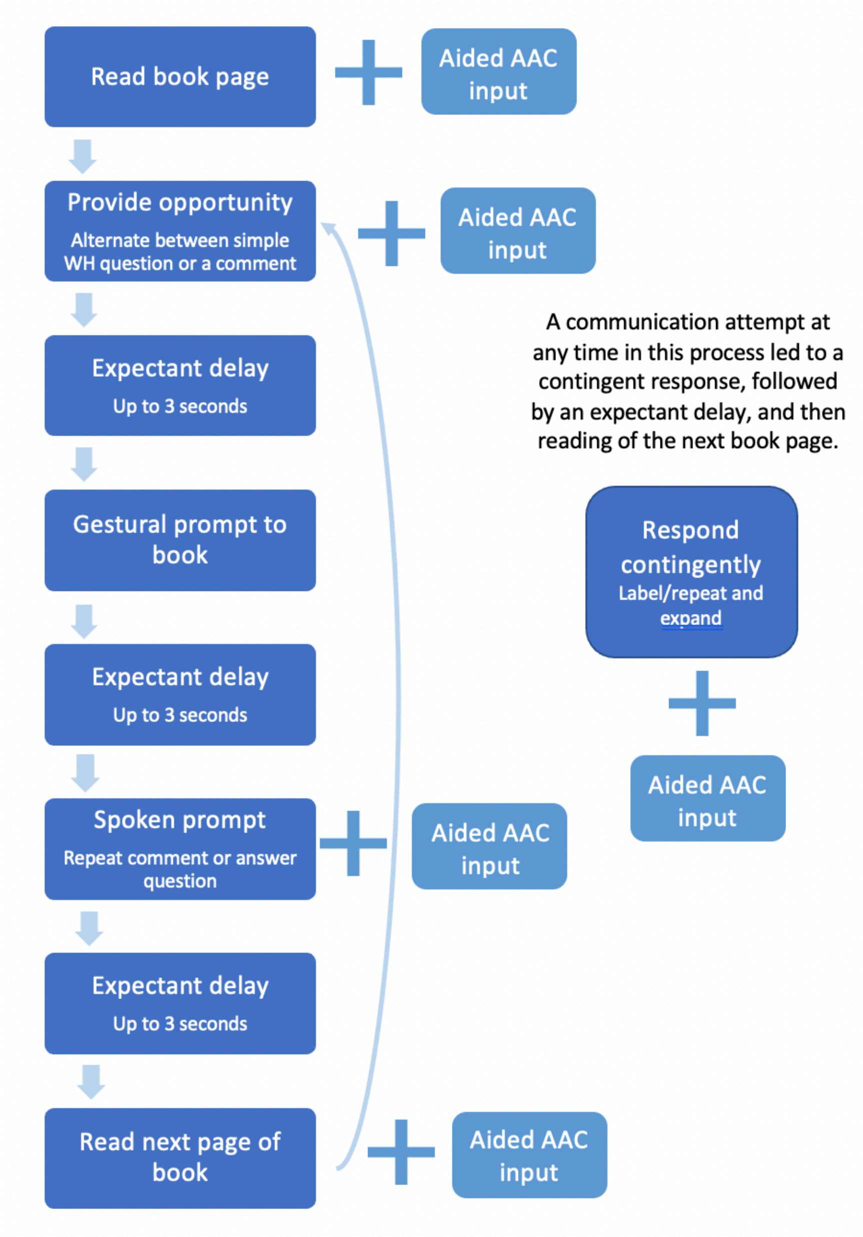

Figure **2-4**: Intervention procedural sequence.

The researcher then completed the process of creating a hotspot on the page within the app (see Figure **2-1**), followed by expanding using speech (e.g., "Elmo snuggles!"), as well as aided AAC, as available (e.g., ELMO + SNUGGLE). On very rare occasions, several participants (Henry, Lila, Lucas, and Teagan) appeared to reject the researcher's attempts to program a concept (e.g., vocalizing in distress, touching the cancel button to stop the programming process, moving to a new storybook page, shaking head "no"). In those instances, the researcher suggested an alternative interpretation of the participant's communication attempt (e.g., "sleep" instead of "Elmo" when the participant indicated the picture of Elmo sleeping). If the participant did not indicate disagreement for this alternative concept, the researcher completed the programming process. If the participant continued to indicate disagreement, the researcher stopped the programing process and continued with the storybook reading activity (though this was extremely rare).

Aided AAC input consisted of the researcher activating a relevant hotspot on the current storybook page immediately following the relevant spoken utterance (e.g., "Elmo sleeps" + SLEEP). The researcher modeled one hotspot via aided AAC input per book page (e.g., "Abby snuggles her doll" + SNUGGLE), as well as activating one hotspot per communication opportunity (e.g., "What is Abby doing?" + ABBY) or spoken prompt (e.g., "Abby is snuggling" + SNUGGLE), given a relevant hotspot was available. The researcher activated at least one hotspot as a part of the expansion component of the contingent response, and up to two relevant hotspots, if available on that page. Evidence suggests that aided AAC input may be more effective when provided asynchronously with speech input (as opposed to simultaneously), though whether it is more supportive before or after the spoken utterance remains unclear (O'Neill et al., 2018).

The majority of hotspots were programmed in response to participants touching an area of interest (e.g., a particular character) within the storybook page. As a result, hotspots were most likely to be programmed as nouns, as nouns are generally the most clearly represented part of speech within an illustration. However, the researcher used all context clues (e.g., the text of the storybook page that had just been read aloud, the nature of any participant gestures or speech approximations) and observed the participant's response to determine what vocabulary to program for a particular hotspot programmed just-in-time.

All hotspots remained within each participant's set of five books from session to session. One participant (Lila) quickly learned the process for programming a hotspot within the app through observing the researcher and she participated actively in drawing and programming many of the hotspots within her set of digital books. She independently selected the button to add a hotspot, drew the hotspot on the storybook page, and attempted to record speech output by vocalizing at the appropriate time. As a result of her independent participation in the programming process, Lila was able to program new vocabulary and was also able to program the same hotspots multiple times across different sessions (e.g., drawing a second hotspot over the picture of Cookie Monster that already had a hotspot). No other participants started to independently engage in the operational programming process, although all participants made communication attempts that initiated the just-in-time programming process.

Each participant had a minimum of five intervention sessions, in line with recommendations for single case research (Kratochwill et al., 2010). All participants in the first leg of the study completed a total of 12 intervention sessions before moving into the maintenance phase, to allow for sufficient time to acquire new concepts. In the second leg, Owen also completed 12 intervention sessions. Due to scheduling conflicts after the end of the school year, Teagan was able to complete a total of nine intervention sessions, and Ian seven.

Maintenance

Maintenance probes were conducted at several timepoints after intervention for all participants in the first leg of the study. Henry and Lila both participated in three maintenance sessions each, and Lucas participated in two maintenance sessions. Henry's maintenance sessions were two, four, and eight weeks after the end of intervention, while Lila's were two, four, and seven weeks after intervention ended. Lucas's maintenance sessions were four and six weeks following the end of intervention. None of the participants in the second leg of the study were able to participate in maintenance sessions as a result of scheduling conflicts. No additional intervention sessions occurred during the maintenance phase. Maintenance sessions were identical to intervention sessions and served as a measure of participant retention of symbolic communication frequency following the end of intervention.

Procedural fidelity

Procedural fidelity was completed by a trained research assistant. The research assistant received training in the procedural steps across all study phases, including practice coding with the first author on study videos not selected for procedural fidelity coding. Once the research assistant attained 90% fidelity with the researcher coding study video not selected for procedural fidelity analysis, procedural fidelity checks were implemented. A randomly selected sample of at least 30% of baseline, intervention, and maintenance sessions were coded for procedural fidelity across each participant. The research assistant watched video recordings of the randomly selected sessions and compared the steps completed by the researcher to the checklist of procedural standards designed for the study. Separate checklists were created for baseline (see Appendix H) and intervention/maintenance (see Appendix I). Checklist items for all NDBI strategies were consistent across phases. Given the naturalistic and child-directed nature of the study procedures, the procedural fidelity checklists were designed to reflect a decision tree, where specific child behaviors should elicit a specific response from the interventionist. Procedural fidelity for each session was calculated by dividing the number of steps completed correctly by the total number of steps completed, then multiplying by 100. Across all participant sessions randomly selected for fidelity coding, procedural fidelity in baseline was 97% (range = 90-99%). Procedural fidelity for all coded sessions in intervention across participants was 96% (range = 90-100%). For maintenance sessions, average procedural fidelity across participants was 97% (range = 96-99%).

Measures and data analysis

Dependent and collateral variables

The primary dependent variable in this study was the total number of relevant, symbolic communicative turns taken by the participant in ten-minute interactions during shared storybook reading. Collateral variables included: (a) cumulative number of unique vocabulary concepts expressed; (b) the communication modality of symbolic turns (e.g., speech, gestures, aided AAC); (c) characteristics of the most frequent expressive vocabulary; (d) characteristics of the vocabulary programmed just-in-time; and (e) comprehension of the spoken word for book-related concepts. All data for the primary dependent variable and collateral measures (a) – (d) were drawn from 10-minute videotaped coding excerpts of the interactions (minutes 2-12) from within each study session. Spoken language comprehension measures were collected during separate probe sessions.

Symbolic communicative turns

The main dependent variable, symbolic communicative turns, was operationalized as in Therrien & Light (2018): (1) spoken words or recognizable speech approximations; (2) conventional gestures (including book-related gestures performed by the researcher); (3) manual signs or recognizable sign approximations; and (4) speech output from an aided AAC system (participant's personal system or the VSD system used in the study – however, it should be noted that no participant took any relevant communicative turns using their personal aided AAC system). Only symbolic communication related to the storybook reading activity was coded (e.g., if the participant asked for a snack during the session, this was not counted). A turn consisted of everything communicated by the participant until either (1) the researcher took a communicative turn or (2) two seconds had elapsed without communication (Laubscher et al., 2019).

However, if the researcher began to respond contingently midway through a participant's connected utterance (i.e., there was *no* discernable pause between multiple concepts communicated by the participant), this was coded as one participant turn. This criterion for determining a connected utterance applied to any expressive modality (i.e., speech, signs/gestures, aided AAC) and could consist of the same concept repeated multiple times (e.g., repeatedly selecting the same hotspot), or combinations of different concepts (e.g., selecting two – or more – hotspots in succession on the same VSD without a discernable pause between selections). However, if the participant discernably paused, and the researcher took a communicative turn during that pause, the next concept communicated by the participant was coded as a new turn, even if it was the same concept as the previous turn (e.g., selection of the same hotspot a second time).

The number of symbolic communicative turns per session was graphed separately for each participant. Level, slope, trend, and variability of the data across phases was assessed using visual analysis, in keeping with the standards for single case research designs (Kratochwill et al., 2010). Each participant's baseline performance was compared to intervention to determine the impact of the independent variable on the number of symbolic communicative turns taken, that is, the impact of adding preprogrammed hotspots within VSDs with digitized speech output, just-in-time programming, and aided AAC input into NDBI procedures. For the first leg of participants, maintenance performance on the primary dependent measure was also compared to baseline to assess whether communication frequency was sustained across time without ongoing intervention. As noted previously, participants in the second leg did not complete maintenance. Effect sizes were calculated for all phase comparisons using Tau-U values (Parker et al., 2011). Tau-U allows for comparisons that include both trend and overlap of values across phases (Parker et al., 2011), making it a relatively sensitive measure in assessing rate of learning over time. By convention, Tau U values of 0.2 represent a small effect, 0.21-0.6 a medium effect, 0.61-0.8 a large effect, and >0.8 a very large effect (Parker et al., 2011).

Unique vocabulary concepts expressed

Data were also collected on the number of unique concepts communicated by participants each session. Unique vocabulary concepts encompassed all modalities of symbolic communication used by the participant (speech, gestures, aided AAC). A vocabulary concept was considered unique if that word (or word root) had not yet been communicated by the participant via any modality over the course of any previous study sessions. For example, if a participant did the manual sign for "eat" during a session, and later activated a hotspot for "eating" within that same session or in a future session, these would be considered the same vocabulary concept, and only count for one unique word in the initial session in which that concept was communicated. Unique concepts were collected as a cumulative measure across sessions – if participants expressed no new concepts in a session, their datapoint for that session would remain at the same value as the previous session. Thus, data for this variable from session to session could either remain at the same level, or increase. The same concept expressed across multiple modalities over the course of the study would only be counted once, the first time it was communicated.

Data for unique vocabulary concepts expressed were graphed separately for each participant. Given the cumulative nature of the data, the slope of the line of best fit was compared across study phases, as a representation of the average rate of new vocabulary use from session to session within each phase (baseline, intervention, and maintenance). Visual analysis also considered any notable changes in level (e.g., a significant increase in unique concepts expressed between two sessions) within and across phases.

If participants communicated more than one unique concept within a single turn *without a discernable pause* between concepts, this was coded as a multi-word utterance, or word combination. Repetitions of a single concept (e.g., repeatedly activating the hotspot for "Elmo;" doing the gesture for *oh no* immediately after selecting the hotspot OH NO) were not coded as word combinations. All unique concepts communicated in succession without a pause were coded as part of the same multi-word utterance. All word combinations were coded for their semantic relationship based on the coding schema from Retherford et al. (1981). Semantic relationships were coded based upon the context of the preceding interaction and the content of the associated storybook page. For example, if Big Bird was giving a present to Cookie Monster within the storybook illustration and in the book text, a word combination of BIG BIRD + PRESENT on that page would be coded as agent + object.

Communication modality

Data were collected on participant communication mode in order to investigate the effects of VSD AAC intervention on spoken language development, as well as participant preference for aided AAC vs. symbolic signs/gestures. Participant communication modalities included speech, aided AAC output, and symbolic signs/gestures. Modality was operationalized at the individual concept level. If participants communicated a multi-symbol utterance that included more than one modality (e.g., ELMO (aided AAC) + *sleep* (gesture)), each individual concept within that utterance was counted separately (e.g., one datapoint for the use of aided AAC, one datapoint for the use of a gesture). Similarly, if participants communicated the same concept within one symbolic turn using multiple modalities (e.g., OH NO (aided AAC) + "Oh no" (speech approximation)), that communicative turn was counted for both modalities used (e.g., one datapoint for aided AAC, one datapoint for speech).

Communication modality for each concept expressed per session was graphed separately for each participant. The average number of concepts communicated per session using each modality (speech, gestures, aided AAC) was calculated for each study phase (baseline, intervention, and maintenance), in order to assess differences in frequency of communication modality use between phases. The total number of unique concepts expressed using each modality across all study sessions was also tallied separately for each participant, as a measure of the relative contribution of each modality to each participant's expressive communication. In contrast to the variable for cumulative unique vocabulary concepts expressed, concepts were counted across modalities each time that they were communicated. For example, if a participant communicated the concept "snuggle" via both gestures and aided AAC over the course of the study, that concept would be counted for both modalities. Additionally, if a participant communicated the same concept multiple times consecutively via the same modality (e.g., repeating the sign/gesture for *sleep* three times repeatedly), each communicative act would count separately for that concept (e.g., counting for a total of three sign/gesture instances of *sleep*).

Characteristics of highest frequency expressive vocabulary

For each participant, the ten most frequently communicated vocabulary concepts combined across all baseline and intervention sessions were calculated. Identified concepts were described in terms of their part of speech (noun, verb, interjection, descriptor), communication modality (speech, gestures, aided AAC), and whether or not the vocabulary concept was programmed just-in-time in response to participant interest. These ten concepts also served as the ten vocabulary items targeted in individualized comprehension probes of spoken language (see *Comprehension measures of spoken language*).

Characteristics of vocabulary programmed just-in-time

Data were collected during each 10-minute videotaped interaction on all vocabulary programmed just-in-time in response to participant interests during intervention and maintenance sessions. Vocabulary programmed just-in-time was analyzed in terms of the total number of unique concepts added during sessions, parts of speech, and the percent of just-in-time vocabulary that was then used expressively by the participant via aided AAC.

Comprehension measures of spoken language

Prior to study initiation, four vocabulary concepts (two nouns and two verbs) were identified within each storybook to be included in comprehension probes of spoken language, for a total of 20 target concepts per participant. Vocabulary for comprehension probes was chosen that: (a) appeared at least twice within the target storybook, (b) was imageable within the storybook page, and (d) overlapped with book related signs/gestures and/or vocabulary identified for preprogrammed hotspots, when possible – in order to maximize the potential for exposure to the spoken word, as well as additional sources of language input (e.g., signs/gestures). Spoken language comprehension probes were completed with participants at three timepoints over the course of the study – before baseline, between baseline and intervention, and after intervention (prior to maintenance). Participant performance on comprehension probes of spoken words prior to the first baseline session served as a proxy for understanding of the targeted concepts before beginning study procedures. Spoken word comprehension probes at the end of baseline served as a measure of participant understanding of the spoken words with exposure to the NDBI procedures within the shared storybook activity. Lastly, participant performance on the probes at the end of intervention served as a measure of additional learning of the target spoken words after exposure to VSD AAC technology and aided AAC input. This task was intended to provide an approximate index of participants' understanding of spoken vocabulary and learning of targeted spoken vocabulary over the course of the study; however, a lack of experimental control limits the strength of the conclusions that can be drawn from these results.

Each participant was probed on their recognition of spoken words for the 20 language concepts identified as comprehension targets across that participant's unique set of five books. Probed vocabulary lists were slightly different for each participant, depending upon their book set, but identical for that participant across the three study timepoints. Target vocabulary within each probe list overlapped, in line with overlap in storybooks across participants. The probes were structured as follows: for each target concept, the participant was shown four images (the target and three foils) while the researcher spoke the target word aloud. The participant was instructed to look at all the pictures and touch the one that matched the spoken word. Vocabulary concepts were represented using the book illustrations themselves (e.g., a picture of Pete the Cat walking for "walk"). All foils were also drawn from that participant's set of 20 vocabulary targets and matched the part of speech of the target (e.g., four verbs, four nouns). For example, the target word "Elmo" might include the foils "pajamas," "cake," and "bus." Comprehension of the spoken word was operationalized as percent accuracy selecting the target concept out of the field of four. Five out of six participants completed this task digitally on an iPad, with each set of four response options presented within a PowerPoint slide. One participant (Owen) completed the task using paper materials, as he was reported to be significantly more comfortable engaging in similar learning tasks with paper materials than on a tablet interface. Accuracy of performance on the spoken language comprehension measure was compared within each participant across all three data timepoints (before beginning baseline, after the end of baseline, and after the end of intervention).

Over the course of the study, participants did not read all books or book pages within their set of five books with consistent frequency, often choosing the same 2-3 storybooks each session. As a result, participants were not exposed to some of the target vocabulary included within the comprehension measure of spoken words with regularity (or at all), providing few opportunities to learn the spoken word for those concepts. As a result, following the end of intervention, each participant also completed an individualized alternative probe task to measure their understanding of the spoken words they communicated most frequently over the course of the study (and thus theoretically the concepts for which participants received the greatest amount of digitized speech output from the aided AAC system). This task was similar in form and structure to the main comprehension probes of spoken language, but featured the ten concepts communicated most frequently by that participant over the course of baseline and intervention. Each vocabulary item was tested twice – once represented using an illustration from the relevant storybook, and once using a digital photograph of the same concept. As this measure was only completed at the end of intervention, the results cannot be used to establish whether participants already had receptive language knowledge of some/all of these spoken vocabulary concepts within their lexicon, or if any were learned over the course of the study. However, the results do offer some preliminary evidence as to whether participants demonstrated knowledge of the spoken words for the concepts that they communicated expressively during the study, as well as whether that knowledge may have been bound to that storybook context specifically or generalized more broadly.

The individualized comprehension measure was evaluated as an index of participant knowledge of the spoken words for the vocabulary concepts each participant communicated most frequently during the course of the study. However, without a comparison prior to intervention procedures, it is unclear to what degree participant performance on this measure was representative of prior underlying knowledge of these spoken words or learning over the course of the study.

Data coding

All sessions were videorecorded for later coding of dependent variables and procedural fidelity. The duration of baseline, intervention, and maintenance storybook reading sessions ranged from approximately 12-20 minutes, dependent upon child engagement and participation that day. To balance across study phases, only a 10-minute segment of each session was coded for all relevant dependent variables, consisting of minutes 2-12 of the total session time (Kasari et al., 2014). All 10-minute coding videos were stored and accessed by the research team on a secure online cloud platform provided by the university. Coding for the primary dependent variable and collateral variables was completed by a trained undergraduate research assistant blind to the goals of the study, with the exception of receptive language probe and individualized comprehension probe performance, both of which were recorded live by the first author. All video coding was completed within the secure online cloud platform interface.

Data reliability

To ensure reliability of the coding of the dependent and collateral variables, a randomly selected sample of at least 30% of baseline, intervention, and maintenance sessions for each participant were coded by a second trained research assistant – a master's student in Communication Sciences and Disorders – blind to the goals of the study, as well as phase and session number of each video. The coding of this second research assistant was compared to the data coding of the first research assistant. Data reliability was completed for the primary dependent variable (number of communicative turns per session), as well as two collateral variables: unique vocabulary concepts expressed and communication modality. If both coders agreed that a session included no symbolic communication, this was coded as 100% agreement for all three outcome variables. Data for both comprehension measures of spoken words were taken live during the activity, though these sessions were also video recorded for later evaluation of data reliability (i.e., interobserver agreement) on participant accuracy. Data reliability coding was also completed by the first trained research assistant for 30% of comprehension of spoken language probe/individualized comprehension probe sessions for each participant. The research assistant's results were compared to the results taken live by the researcher.

Data reliability for the primary dependent variable (number of symbolic communicative turns) was completed on a turn-by-turn basis. Agreement between coders was noted if both coders recorded that a turn occurred within a five second window. Data reliability was calculated per participant per session by dividing the number of agreements by the total number of agreements plus disagreements plus omissions, then multiplying by 100. The average data reliability for number of symbolic turns across participants was 84% (range = 50%-100%) in baseline, 82% in intervention (range = 75%-92%), and 78% in maintenance (range = 73%-88%).

Table **2-3**: Average reliability for each measure by participant and study phase.

Measure	Phase	Henry	Lila	Lucas	Owen	Teagan	Ian
Symbolic communicative turns	BL	84%	84%	81%	100%	50%	100%
	Int	81%	85%	78%	79%	75%	92%
	Maint	73%	73%	88%	–	–	–
Unique vocabulary concepts expressed	BL	100%	88%	88%	100%	50%	100%
	Int	84%	92%	85%	88%	92%	100%
	Maint	78%	88%	100%	–	–	–
Communication modality	BL	100%	100%	100%	100%	100%	100%
	Int	100%	100%	96%	92%	100%	100%
	Maint	100%	100%	100%	–	–	–
Comprehension of spoken words		100%	100%	100%	100%	90%	100%
Individualized post-hoc comprehension of spoken words		100%	100%	100%	100%	–	–

Note. BL: baseline; Int: intervention; Maint: maintenance

Data reliability values by participant for each included variable across study phases can be found in Table **2-3**. For each outcome variable (e.g., symbolic communicative turns), the average percent agreement was taken for all videos designated for reliability coding within a phase (e.g., baseline) for each participant (e.g., Henry), as a measure of the average data agreement for that phase (e.g., Henry's average percent agreement for symbolic communicative turns in baseline). All disagreements were resolved through discussion between the first author and two trained research assistants.

Given the low rates of symbolic communication for most participants in baseline (as well as during a number of individual intervention sessions), several sessions identified for data reliability coding contained less than five total symbolic turns, and often were comprised exclusively of idiosyncratic gestures or speech approximations. As a result, a difference of opinion on the symbolic nature of 1-2 participant vocalizations or gestures between the two data coders could substantially impact the reliability score for that session. This was the case for all baseline sessions identified for reliability coding for Teagan. Each session only contained three or fewer symbolic communicative turns, but the two data coders disagreed on 1-2 of those turns, resulting in a low overall reliability percentage for that study phase of 50% for both symbolic communicative turns and unique vocabulary concepts expressed. However, given the very low rates of symbolic communication in these sessions, a difference of 1-2 communicative turns would not have had a significant impact on the overall baseline trend. Additionally, a difference of 1-2 turns represents a small numerical value of discrepancy. As only turns identified by both coders could be assessed for agreement in terms of communication mode, this discrepancy did not affect baseline data reliability for this outcome measure.

Data reliability for unique vocabulary concepts expressed was calculated for each session by taking the expressive concepts identified by both coders (agreements), divided by the total number of unique concepts identified across both coders for that session, then multiplying by 100. If the same concept was communicated multiple times by a participant within a session, it was considered agreement if both coders indicated that the concept was communicated at least once. The average data reliability for unique vocabulary concepts expressed across participants was 88% (range = 50%-100%) in baseline, 90% in intervention (range = 84%-100%), and 89% in maintenance (range = 78%-100%).

Data reliability for communication mode was also calculated on a turn-by-turn basis. For each turn identified by both coders, agreement was assessed regarding the mode indicated (speech, gestures, or aided AAC). If multiple concepts were communicated within a single symbolic turn (e.g., ELMO (aided AAC) + “sleep” (speech approximation)), each concept was assessed separately for agreement between both coders. Data reliability was calculated per participant per session by dividing the number of agreements by the total number of agreements + disagreements + omissions across both coders, then multiplying by 100. The average data reliability for communication mode across participants was 100% (range = 100%-100%) in baseline, 98% in intervention (range = 92%-100%), and 100% in maintenance (range = 100%-885). All disagreements on this measure were a result of one coder designating an identified symbolic turn as multimodal (e.g., “sleep” communicated in one symbolic turn using both aided AAC and a gestural approximation), while the other coder only indicated one communication mode for that same communicative turn.

Data reliability for both comprehension measures of spoken language were calculated on trial-by-trial basis. Data reliability was calculated per participant by dividing the number of agreements by the total number of agreements + disagreements across both coders, then multiplying by 100. The average data reliability for the main spoken language comprehension probes across participants was 98% (range = 90%-100%). The average data reliability for the individualized post-hoc spoken language comprehension probes across participants was 100% (range = 100%-100%).

Caregiver social validity

Social validity was completed with participating caregivers. Each caregiver was shown two separate five-minute video clips of their participating child – one clip from intervention, and one clip from baseline. Video clips for each participant were randomly selected from the last three sessions of baseline and intervention, respectively. Within each video, minutes 3-8 were selected for viewing by caregivers. The order of presentation was counterbalanced across caregivers – half of the caregivers were randomly assigned to view the video clip from baseline first, and the other half to view the clip from intervention first. Caregivers viewed each video clip, then were asked to complete a short questionnaire that included questions regarding their opinions on the importance, effectiveness, feasibility, and child engagement in the activity (see Appendix J). Following completion of the two separate questionnaires for baseline and intervention, caregivers were asked to fill out a final, two-question forced choice questionnaire comparing the video clips of the two phases. Participants were not informed about which video clip came from which study phase but were unlikely to be blind to the goals of the study as these were explained as part of the informed consent process.

Chapter 3

Results

As previously noted, all data are drawn from 10-minute coding excerpts (minutes 2-12) of the videotaped interactions from each study session. Characteristic of a multiple probe design, baseline phase length varied by participant, ranging from 5 sessions (Henry and Owen) to 14 sessions (Lucas), dependent upon where in each leg of the study the participant fell. The total time engaged in NDBI storybook reading sessions in baseline thus ranged across participants from 75 to 210 minutes (1.25 hours – 3.5 hours).

The intervention phase for all participants in the first leg of the study consisted of 12 sessions, resulting in approximately 180 total minutes of intervention (3 hours) per participant, consisting of NDBI storybook reading with the addition of AAC hotspots with digitized speech output, just-in-time programming of concepts in response to participant interests, and aided AAC input (i.e., the researcher activating relevant hotspots within the storybook to augment speech input to the participant). Participants in the first leg of the study also all completed several maintenance sessions apiece at two- to three-week intervals following the end of intervention (Henry and Lila = 3 sessions; Lucas = 2 sessions). Due to scheduling constraints at the end of the school year, participants in the second leg of the study completed 7 (Ian), 9 (Teagan), and 12 (Owen) intervention sessions and were not available to participate in maintenance sessions. Thus, they experienced 105 to 180 minutes total of intervention.

Symbolic communicative turns

The primary dependent variable in this study was the total number of relevant, symbolic communicative turns taken by the participant within each 10-minute video. It was hypothesized that participants would take few to no turns in baseline but might experience a gradual increase in the number of turns taken per session over the course of baseline, given the support of NDBI strategies and modeled gestures. However, it was hypothesized that participants would take significantly more turns in intervention compared to baseline, given the addition of VSD AAC, just-in-time programming, and aided AAC input by the researcher.

All participants experienced an overall increase in the number of communicative turns taken per session from baseline to intervention, in line with the research hypothesis (see Figures **3-1** and **3-2**). Effect sizes ranged from 0.24 to 1 across participants, indicating a medium to very large effect of the intervention on the number of symbolic communicative turns for participants (see Table **3-1**). The majority of turns were single words, but all participants started to take communicative turns that consisted of two-word combinations during intervention, by activating two hotspots in succession on the same VSD (e.g., OH NO + ALL GONE; BERT + BRUSH; GROVER + PAJAMAS).

As is typical with children on the autism spectrum, participant performance within and across study phases was somewhat variable. However, all but one participant demonstrated a consistent low level of turns or a downward trend in baseline. Teagan was the only participant to show evidence of an upward trend in baseline, attributable almost entirely to her repeated use of the “sleep” gesture modeled by the researcher. Taken together, these results suggest that NDBI strategies alone (including modeled gestures) were not generally associated with a steady increase in symbolic communication for most participants. However, with the addition of VSD AAC, just-in-time programming, and aided AAC input during intervention, participants showed either an increasing upward trend and/or a significant jump in level from baseline to intervention in their number of symbolic communicative turns per session. Intervention levels of communicative turns remained consistent in the maintenance phase for the three participants who were available to participate in maintenance sessions (Henry, Lila, and Lucas).

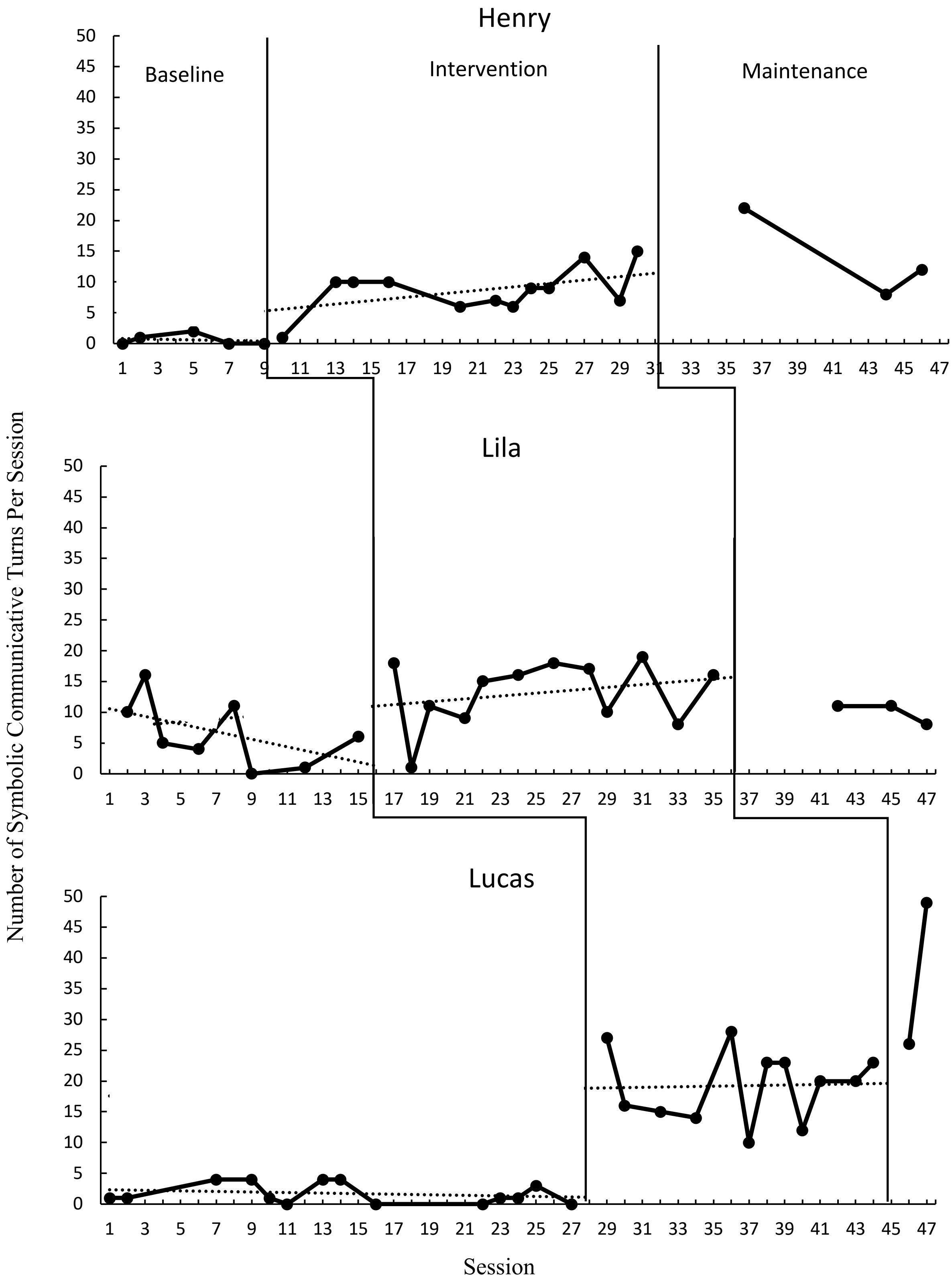

Figure **3-1**: Symbolic communicative turns per 10-minute session, including trend lines of best fit for baseline and intervention (leg 1; concurrent baseline).

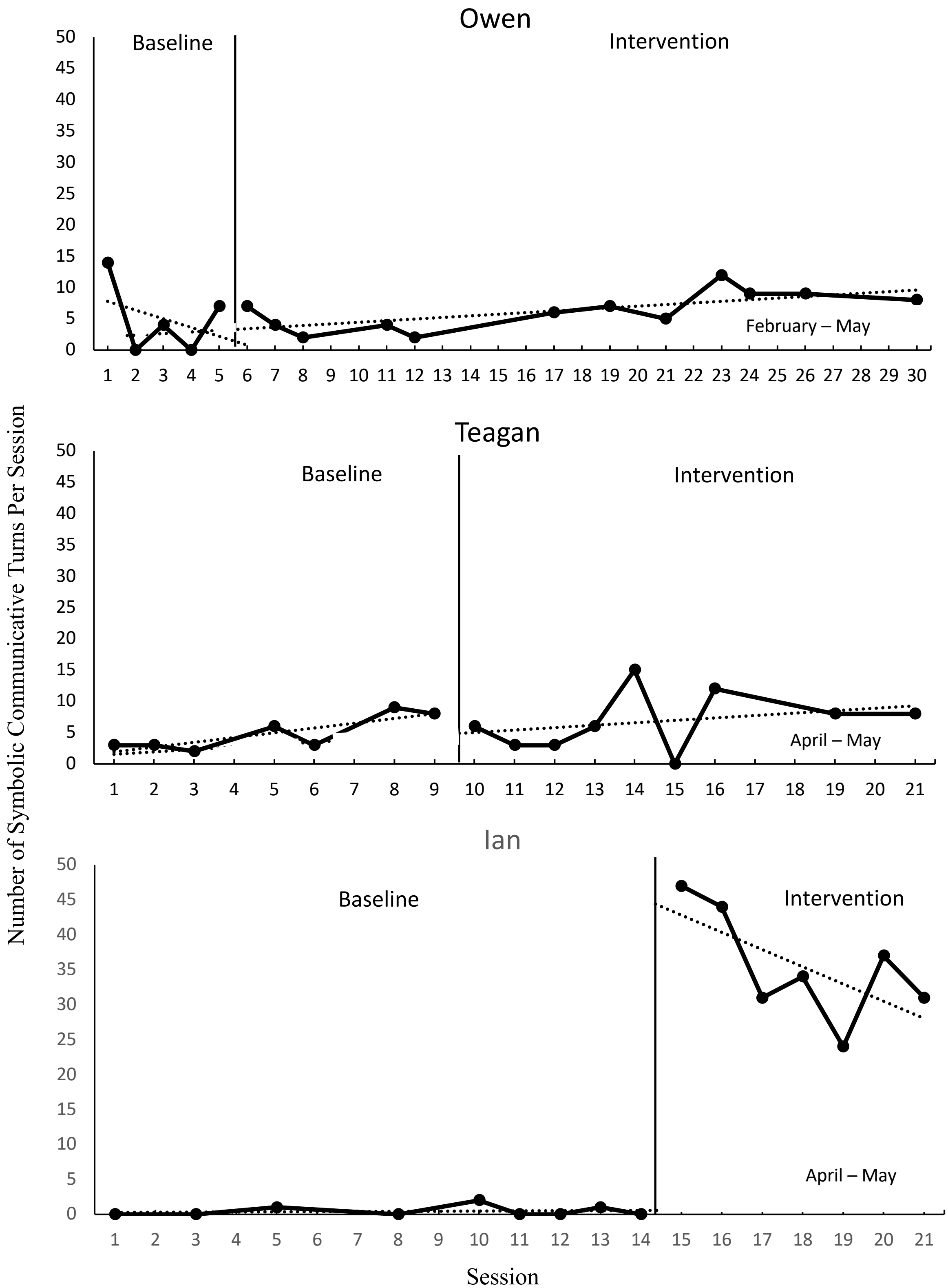

Figure **3-2**: Symbolic communicative turns per 10-minute session, including trend lines of best fit for baseline and intervention (leg 2, nonconcurrent baseline).

Table **3-1**: Mean number of symbolic communicative turns during all phases and Tau-U effect sizes.

Participant	**Mean # of symbolic communicative turns in 10 minutes**			**Tau-U**	
	Baseline	Intervention	Maintenance	BL to Int	BL to Maint
Henry	0.6	8.7	14	0.95	1
Lila	6.6	13.2	10	0.61	0.52
Lucas	1.7	20	37.5	1	1
Owen	5	6.3	–	0.40	–
Teagan	4.9	6.8	–	0.24	–
Ian	0.4	35.4	–	1	–

Note. BL: baseline; Int.: intervention; Maint.: maintenance; Tau-U: small = 0.2; medium = 0.21-0.6; large = 0.61-0.8; very large = >0.8; Vannest & Ninci, 2015)

Henry

During baseline sessions with NDBI strategies only, Henry took only a few symbolic communicative turns (see Figure **3-1**). His performance was consistent, demonstrating little variability or trend in either direction. In three out of five baseline sessions, he did not take any symbolic turns, and averaged 0.6 turns per session. Following the first intervention session, Henry's number of symbolic communicative turns increased significantly. Across the intervention phase, with the addition of VSD hotspots, just-in-time programming, and aided AAC input to NDBI procedures, he took an average of 8.7 turns per session, with a maximum of 15 turns in one session. Henry's performance during intervention demonstrated an overall upward trend, with some variability across sessions. Only the first intervention point overlapped with Henry's baseline level of symbolic turns. The effect size from baseline to intervention was 0.95, indicating a very large effect of the intervention on Henry's frequency of symbolic communication (Vannest & Ninci, 2015). Henry maintained his higher communicative rate during maintenance, taking an average of 14 symbolic turns, with a maximum of 22 turns in one maintenance session. The effect size from baseline to maintenance was 1, indicating that the very large effect of the intervention on Henry's frequency of symbolic communication remained consistent over time without frequent intervention sessions.

Lila

Lila demonstrated a variable, but overall descending, trend in terms of the number of symbolic communicative turns per session in baseline (see Figure **3-1**). During baseline, she quickly caught on to the symbolic signs and gestures modeled by the researcher during the shared reading activity, often imitating the researcher's signs/gestures as well as spontaneously communicating those concepts via gesture. This high rate of signs/gestures was most notable in the first two baseline sessions, with a maximum of 16 turns in the second baseline session. Her use of these symbolic signs and gestures then declined over the course of baseline, reaching a low of 1-2 communicative turns per session. On average, Lila took 6.6 turns across all baseline sessions.

Despite the overall descending slope in baseline, Lila did have a slight upward trend in the final baseline session. This upward trend at the end of baseline reduces the strength of the conclusion that Lila's higher intervention performance reflects an effect of the intervention itself, as opposed to a continuation of this upward trend from the final baseline point. However, her number of symbolic turns for that final baseline session (6 turns) was still well below both her initial baseline performance as well as her average number of symbolic turns during intervention (13.2 turns). Additionally, her first intervention session represented a substantial jump in symbolic communication (18 turns) and all but one intervention point was higher than her final baseline session.

Lila's number of communicative turns per session continued to demonstrate variability during intervention, but with an overall upward trend. Her symbolic communication in the second intervention session was a notable outlier, as Lila took only one symbolic communicative turn. During this session, Lila began to initiate the steps of programming hotspots on the VSD system independently (i.e., touching the button to program a hotspot and drawing around concepts on the storybook pages), and she spent the majority of the session focused on drawing new hotspots to add vocabulary (11 total hotspots added in that session). The novelty of the programming process appeared to detract from her use of the new vocabulary expressively in that session. However, her frequency of symbolic turns increased again in the following session.

Given Lila's high rates of gestural communication in several baseline sessions, there was overlap between her baseline and intervention performance. However, overall, she took an average of 13.2 turns per session during intervention, double her average number of turns in baseline. The effect size from baseline to intervention was 0.61, indicating a large effect of the intervention on the number of Lila's symbolic communicative turns per session (Vannest & Ninci, 2015). The effect size from baseline to maintenance was 0.5, in the upper range of a medium effect. Lila took an average of 10 turns per session during the maintenance phase, still notably higher than her average turn frequency of 6.6 in baseline.

Lucas

Lucas demonstrated a very low level of symbolic communication during baseline, ranging from 0-4 turns per session (see Figure **3-1**). In almost two thirds of baseline sessions, Lucas took one symbolic turn or less. He averaged 1.7 turns per session during baseline. Lucas demonstrated an immediate substantial increase in his symbolic communication in the first intervention session, taking 27 communicative turns. Across the intervention phase, he took an average of 20 turns per session, with a maximum of 27 turns in the first intervention session. Lucas's intervention performance was somewhat variable, ranging from 10-27 turns per session. However, the frequency of symbolic turns in 100% of intervention sessions were significantly higher than his highest baseline point. The effect size from baseline to intervention was 1.0, indicating a very large effect (Vannest & Ninci, 2015). The effect size from baseline to maintenance was also 1.0, indicating that Lucas continued to demonstrate higher rates of symbolic communication during maintenance as compared to baseline. His mean number of turns in maintenance also increased from baseline to intervention, with an average of 37.5 communicative turns per session.

Owen

Owen's baseline length was randomly preset to five sessions as a part of the nonconcurrent leg of the study. His baseline performance showed variability, ranging from 0-14 turns per session with an average of 5 symbolic communicative turns over the baseline phase (see Figure **3-2**). However, all of Owen's communicative turns in baseline represented him repeatedly communicating a single concept (a gesture approximation of the sign for ringing a bell). Following the first three intervention sessions, Owen began to steadily increase his number of communicative turns per session, which corresponded with his initial uptake of VSD AAC as a communication modality in the fourth intervention session. He took an average of 6.3 symbolic turns per session in intervention and a maximum of 12. The effect size from baseline to intervention was 0.4, indicating a medium effect of the intervention (Vannest & Ninci, 2015). Given the relatively high number of communicative turns in Owen's first baseline session, no data points in intervention exceeded this number.

Owen experienced greater fine motor challenges successfully selecting a hotspot than the other participants, which impacted his number of turns per session in intervention. Eight out of his total 12 intervention sessions included at least three or more instances where Owen attempted to activate a hotspot within the storybook page, but without successfully making the selection to trigger the speech output. One single intervention session included eight unsuccessful hotspot activation attempts. The protocols for this study only measured successful hotspot activations resulting in speech output as symbolic communicative turns. Had Owen been successful in activating the hotspot speech output in these attempts during intervention, his average number of communicative turns in this phase would have increased to 9.6 (rather than 6.3).

Teagan

Teagan's baseline length was randomly preset to seven sessions as a part of the nonconcurrent leg of the study. Teagan demonstrated a consistently low level of symbolic communicative turns across the first three sessions in baseline (see Figure **3-2**). She experienced a slowly increasing trend at the end of baseline, as a direct result of her repeatedly communicating the gesture approximation for "sleep." All but one communicative turn in each of Teagan's final two baseline sessions consisted of the gesture for "sleep." Overall, her number of turns per session in baseline ranged from 2-9, with an average of 4.9 turns. Teagan's first four intervention sessions remained in the range of her baseline performance, with a subsequent jump in her number of communicative turns in the fifth intervention session. This jump coincided with Teagan's more robust expressive use of the VSD AAC system. Her communication frequency for the final five intervention sessions remained at or above her highest baseline level, with an average of 7.1 communication turns pers session – aside from the notable exception of the sixth intervention session. During this session, the researcher was wearing a mask for infection control precautions. Teagan appeared very distressed by this change, vocalizing loudly and frequently attempting to remove the researcher's mask during the session, potentially contributing to her low number of communicative turns. Teagan's overall Tau-U from baseline to intervention was 0.29, indicating a medium effect of the intervention on her number of symbolic communicative turns per session.

Ian

Ian's baseline length was randomly preset to nine sessions as a part of the nonconcurrent leg of the study. Ian took only four symbolic communicative turn over the course of the entire baseline phase (see Figure **3-2**). He experienced a very significant jump in his expressive communication starting in the first intervention session, taking 47 communicative turns. Ian maintained a high number of communicative turns throughout the intervention phase, though with a decreasing trend across the phase. However, his lowest frequency of symbolic communicative turns during intervention was 24 – a significant change in level from his highest baseline session with two communicative turns. This downward trend in intervention may be a result of the initial novelty of gaining access to the VSD AAC system, resulting in an elevated turn-taking frequency in the first few sessions. He took an average of 35.4 turns during intervention, with a Tau-U of 1.0 from baseline to intervention, indicating a very large effect

(Vannest & Ninci, 2015). All of Ian's intervention sessions included a significantly greater number of communicative turns than his highest baseline session.

Unique vocabulary concepts expressed

Analyses also explored the impact of the intervention on the cumulative number of unique vocabulary concepts expressed by participants within the 10-minute coding session excerpts as a measure of expressive vocabulary growth (see Appendix K for a comprehensive list of unique vocabulary concepts expressed by each participant). A vocabulary concept was considered unique if that word (or word root) had not yet been communicated by that participant over the course of the study, in any study phase. For example, if a participant did the manual sign for "eat" during a session, and later activated a hotspot for "eating" within that same session or in a future session, these would be considered the same vocabulary concept, and only count for one unique word in the initial session in which that concept was communicated. It was hypothesized that participants would show a small degree of growth in their number of unique vocabulary concepts expressed in baseline, via imitation of signs/gestures modeled by the researcher. However, participants were expected to plateau in the number of unique vocabulary concepts expressed in baseline, given the finite number of signs/gestures performed by the researcher. It was further hypothesized that participants would demonstrate a significant increase in the rate of unique vocabulary growth during intervention, with access to VSD AAC, just-in-time programming, and aided AAC input.

The rate of change in cumulative number of unique vocabulary concepts expressed was measured by taking the slope of the line of best fit for data in each study phase, respectively. All participants but one (Lila) experienced minimal overall growth in their expressive vocabulary during baseline, with slopes less than 1, and most at or below 0.5 (see Table **3-2**). Every participant did imitate at least one modeled sign/gesture in baseline, and all but one participant (Owen) added at least one additional expressive concept to their repertoire during the baseline phase. As hypothesized, all participants reached a plateau in their unique vocabulary concepts expressed during baseline, adding few to no new vocabulary concepts after the first few sessions (see Figures **3-3** and **3-4**). In line with the study hypothesis, all participants showed an increased growth rate (i.e., a larger slope) in their expressive vocabulary development during intervention as compared to baseline – though this increase was modest for two participants (Lucas and Teagan). All three participants who participated in maintenance sessions continued to increase their vocabulary growth during this phase, at a rate greater than their baseline performance.

Table **3-2**: Slope of the line of best fit for total unique concepts expressed by study phase.

Participant	**Slope**		
	Baseline	Intervention	Maintenance
Henry	0.5	1.9	1
Lila	1.5	3.6	2
Lucas	0.4	0.9	2
Owen	0	2.2	–
Teagan	0.8	1.4	–
Ian	0.3	4.1	–

Note. The slope represents the rate of growth of unique vocabulary concepts over time in that phase.

Two-word combinations

Along with single word expressive concepts, all participants communicated at least one two-word combination using two hotspots on the same storybook page by selecting the hotspots in immediate succession (see Table **3-3** and Appendix K). However, the overwhelming majority of symbolic turns consisted of single words/concepts. While aided AAC combinations were often modeled by the researcher during intervention and maintenance in the context of language expansions, supporting two-word combinations was not a formal goal of the study. Participants varied in terms of the total number of combinations expressed during intervention (from one to seven combinations) and the number of intervention sessions completed prior to their first two-word combination (from one session to eleven sessions), as well as the number of unique book-related vocabulary concepts they had used expressively prior to their first two-word combination (from 10 concepts to 30 concepts). Aided AAC combinations were predominantly agent + action (e.g., COOKIE MONSTER + BITE) or agent + object (e.g., BERT + TEETH). Participants were only observed to make these kinds of novel, generative utterances using aided AAC (not via gestures or speech).

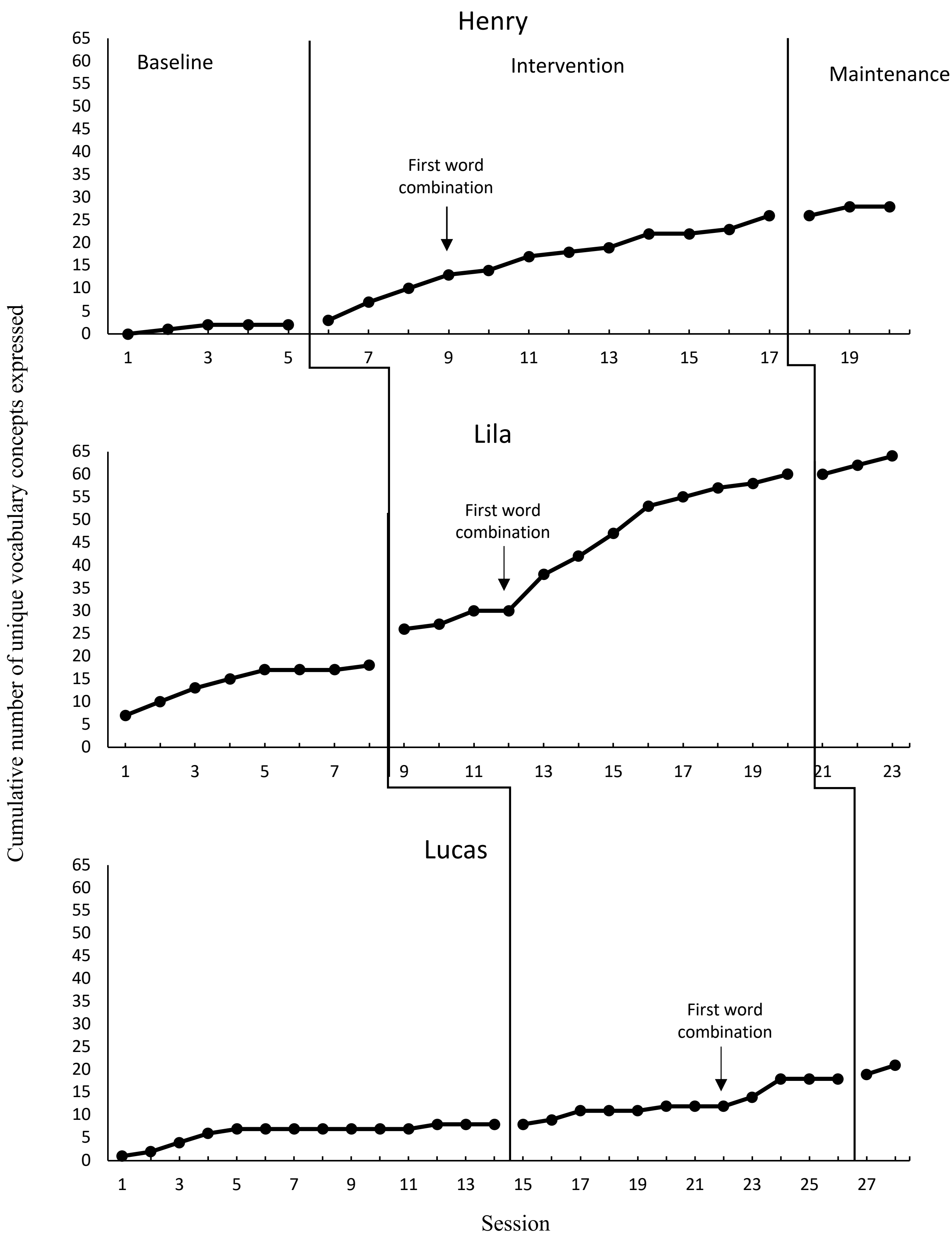

Figure **3-3**: Cumulative number of unique vocabulary concepts expressed (leg 1; concurrent baseline).

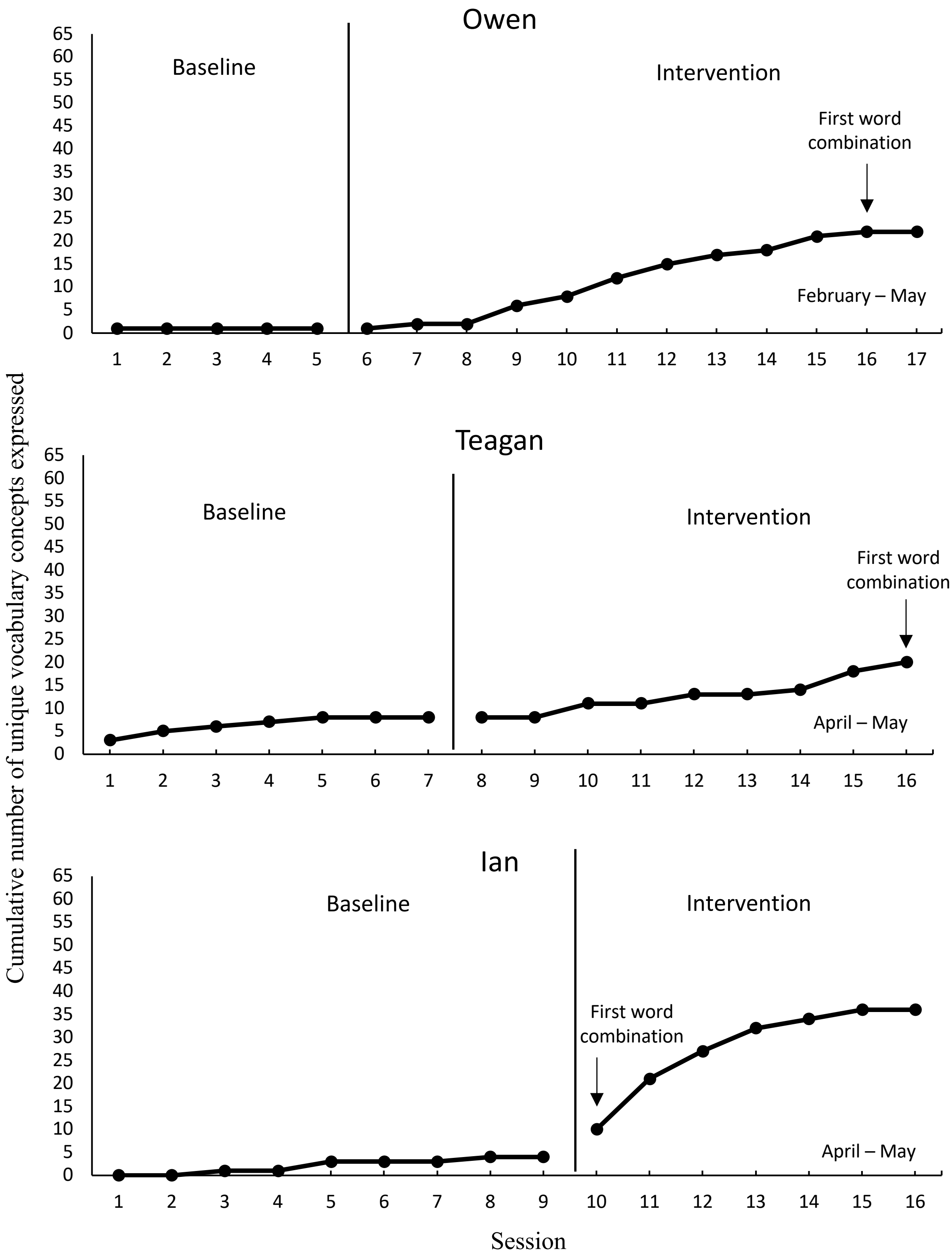

Figure **3-4**: Cumulative number of unique vocabulary concepts expressed (leg 2; nonconcurrent baseline).

Table **3-3**: Word combinations communicated by participants during intervention and/or maintenance.

Participant	Word combination	Semantic relationship	Mode
Henry	Bert + teeth	Agent + object	Aided AAC
Lila	Bite + Cookie Monster (3x)	Action + agent	Aided AAC
	Cookie Monster + present	Recipient + object	Aided AAC
	Sprinkles + white chocolate + chocolate chips	Entity + entity + entity	Aided AAC
	Oh no + all gone	Negation + negation	Aided AAC
Lucas	Sleep + Baby David	Action + agent	Aided AAC
	Swings + oh no	Object + negation	Aided AAC
	Snuggle + Abby (2x)	Action + agent	Aided AAC
	Snuggle + Baby David	Action + object	Aided AAC
	Abby + doll	Agent + object	Aided AAC
Owen	Firehouse + school bus	Entity + entity	Aided AAC
Teagan	Grover + Ernie	Entity + entity	Aided AAC
	Grover + Big Bird	Entity + entity	Aided AAC
	Cookie Monster + bite	Agent + action	Aided AAC
Ian	Grover + present	Agent + object	Aided AAC
	Door + Grover + door	Locative + entity + locative	Aided AAC
	Grover + door	Entity + locative	Aided AAC
	Cake + Cookie Monster	Object + agent	Aided AAC
	Bus + firehouse	Entity + entity	Aided AAC
	Cake + open + cake	Object + action + object	Aided AAC
	Open + cake	Action + object	Aided AAC

Note. Semantic relationships are based on the coding schema set forth by Retherford et al. (1981) and reflect both the parts of speech of each concept expressed, as well as the context of interpretation (i.e.., the particular storybook page)

Henry

Henry was only observed to use two different concepts expressively in baseline: ring (bell) and brush (teeth). These were both gestures modeled by the researcher during shared storybook reading. Henry's baseline performance for unique expressive vocabulary was relatively flat, with a slope of 0.5, indicating minimal growth in the concepts that he used expressively in shared storybook reading sessions during this phase. During intervention, when provided with access to AAC hotspots, just-in-time programming, and aided AAC input in the context of NDBI procedures, Henry began to increasingly use new expressive vocabulary, communicating 24 new concepts in this phase over the course of 180 minutes of intervention. He communicated at least one new vocabulary concept in every intervention session but one. The slope for his intervention performance was 1.9, a notable change from his rate of vocabulary growth in baseline. During the maintenance phase, his rate of new vocabulary use remained higher than in baseline, with a slope of 1. Henry communicated one two-word combination via aided AAC (BERT + TEETH) during intervention, in the fourth intervention session; no two-word combinations were observed at baseline. He had communicated 13 different book-related vocabulary concepts prior to producing a two-word combination. Henry's family did not report his use of two-word combinations at study initiation.

Lila

Lila experienced some initial quick growth in the number of unique vocabulary concepts she expressed during baseline, communicating 10 new concepts from the first to the fifth baseline session. Across all of baseline, the majority of Lila's expressive vocabulary (15 out of 18 concepts) was comprised of gestures modeled by the researcher. This aligned with Lila's reported skills of quickly picking up new signs following 1-2 models. However, Lila's rate of vocabulary growth slowed substantially in the second half of baseline, with her communicating only one additional vocabulary concept total in the final four baseline sessions. Her overall slope for unique vocabulary concepts expressed in baseline was 1.5, attributable in large part to her initial quick uptake of modeled signs and gestures. Only the same set of predetermined signs/gestures were modeled by the researcher for each book, potentially limiting Lila's opportunity to learn new expressive concepts in baseline. However, a total of 23 unique book-related signs/gestures were available to Lila within her set of five storybooks (five signs/gestures per book, with two overlapping across books). Over the course of baseline, Lila communicated only 13 of these book-related signs/gestures at least once – slightly more than half – and at an overall decreasing rate.

Lila's rate of expressive vocabulary growth during intervention increased substantially. She communicated 42 new concepts during this phase over the course of 180 total minutes of intervention, with an overall slope of 3.6. This indicated a significant increase in her rate of vocabulary growth, as compared to baseline. Lila consistently communicated new expressive vocabulary in all but one session during intervention. Over half of these concepts (26) were programmed as hotspots just-in-time, often by

Lila herself. After the first intervention session, Lila had already learned the following steps of programming a hotspot from observing the researcher, and frequently performed them independently during intervention sessions: (a) touching the button to start the process of programming a hotspot; (b) circling a target concept on the storybook page; and (c) recording audio for the hotspot by vocalizing at the appropriate moment (additional recorded audio for the hotspot was also spoken by the researcher).

Across the maintenance phase, Lila's unique vocabulary added per session had a slope of 2, intermediate between her baseline and intervention vocabulary growth rate, but showing continued positive growth. Lila communicated four two-word combinations via aided AAC, starting in the fourth intervention session. Semantic relations for these word combinations included action + agent (e.g., BITE + COOKIE MONSTER) and recipient + object (e.g., COOKIE MONSTER + PRESENT). No two-word combinations were observed at baseline. Lila had communicated 30 different book-related vocabulary concepts prior to producing her first two-word combination. Lila's family reported that she did combine two novel concepts infrequently at study initiation, mostly via sign language.

Lucas

Lucas experienced a slow increase in his expressive vocabulary over the course of the study. In baseline, most of his vocabulary growth occurred in the first five sessions (from one concept to seven), then remained relatively flat for the remainder of the baseline phase (sessions 6-14). His overall slope for unique vocabulary concepts expressed in baseline was 0.4, indicating limited growth over time. Lucas had a modest increase in his rate of unique vocabulary concepts expressed during intervention, with a slope of 0.9. He communicated a total of 10 new concepts in 12 sessions (180 minutes) over the course of intervention (as compared to seven new concepts over the course of 14 sessions and 210 total minutes in baseline). Lucas added concepts more rapidly during intervention than in baseline, especially in the last few intervention sessions. During the maintenance phase, his rate of new vocabulary use increased as compared to intervention, with a slope of 2. Lucas communicated five different two-word combination via aided AAC, starting in the eighth intervention session. Semantic relations for these word combinations included action + agent (e.g., SLEEP + BABY DAVID) and agent + object (ABBY + DOLL). Lucas had communicated 12 different book-related vocabulary concepts prior to producing a two-word combination. No two-word combinations were observed at baseline, and Lucas's family did not report his use of two-word combinations at study initiation.

Owen

Owen communicated only one concept expressively during baseline – a gesture approximation of the sign for ringing a bell, one of the signs modeled by the researcher during shared storybook reading. Owen's baseline performance for unique expressive vocabulary thus demonstrated no growth, with a slope of 0. During intervention, Owen began to steadily add new concepts to his expressive vocabulary, with a slope of 2.2. Interestingly, these new vocabulary items included aided AAC output from the VSD hotspots, signs/gestures modeled by the researcher, and speech approximations. Owen communicated at least one new vocabulary concept in every intervention session but two. By the end of the intervention phase, he had expressed 21 new concepts over the course of 180 minutes of intervention. Owen communicated one two-word combination via aided AAC (FIREHOUSE + SCHOOL BUS) in the 11th intervention session; no two-word combinations were observed at baseline. He had communicated 22 different book-related vocabulary concepts prior to producing a two-word combination. Owen's family reported that he communicated a small corpus of spoken phrase approximations (e.g., "I done"), but that he did not use generative two-word combinations at study initiation.

Teagan

Teagan demonstrated initial growth in her expressive vocabulary during baseline, adding 1-2 unique concepts per session for the first four sessions. However, she reached a plateau for the last three sessions of baseline, adding no new vocabulary to her expressive communication. Her overall slope for vocabulary growth in baseline was 0.8. During intervention, Teagan's rate of vocabulary growth increased from the baseline phase (slope of 1.4 in the intervention phase), with her communicating 2-3 new concepts every couple of sessions; her rate started to increase more rapidly in the last two intervention sessions. At the end of intervention, she had communicated 12 additional unique concepts over the course of 180 minutes of intervention, as compared to 8 total unique vocabulary concepts in baseline. Teagan communicated three different word combinations via aided AAC, all in the 9th intervention session. Semantic relations for these word combinations included entity + entity (e.g., GROVER + ERNIE) and agent + action (COOKIE MONSTER + BITE). Teagan had communicated 20 different book-related vocabulary concepts prior to producing a two-word combination. No two-word combinations were observed at baseline, and Teagan's family did not report her use of two-word combinations at study initiation.

Ian

Ian used only four unique vocabulary concepts expressively over the course of nine baseline sessions. The overall slope for Ian's vocabulary in baseline was 0.3. With access to aided VSD AAC, just-in-time programming, and aided AAC input during intervention, Ian immediately started to communicate a wider range of concepts, communicating 8-10 new concepts in each of the first few intervention sessions. The overall slope for Ian's vocabulary growth during intervention was 4.1 – a substantial increase from his baseline performance. Ian communicated four different word combination via aided AAC, starting in the first intervention session, representing a variety of different relationships (e.g., agent + action; agent + object). No two-word combinations were observed at baseline. Ian had communicated 10 different book-related vocabulary concepts prior to producing a two-word combination. Ian's family reported at study initiation that he would infrequently communicate using a generative two-word combinations, via speech approximations.

Communication modality

The goal of this measure was to explore what modes participants used to express themselves. It was hypothesized that, in baseline, participants would communicate limited concepts via speech (given caregiver report and observations during natural language samples), relying predominantly on book-related signs/gestures. During intervention, it was hypothesized that participants would communicate concepts via speech at a similar rate, as evidence suggests that aided AAC does not appear to have any negative impact on speech development (Millar et al., 2006; Schlosser & Wendt, 2008). It was hypothesized that participants would continue to use gestures during intervention, but potentially at a decreased rate, given the availability of aided AAC in the form of VSD hotspots within the digital books.

VSD AAC was expected to be the most prevalent mode of communication during intervention, given the ease of learning and use of the VSD system. Activating a hotspot within a storybook page in the AAC app required less fine motor control than most book-related gestures/signs. Additionally, the storybook display provided contextual support for communication; participants were not required to shift attention between the storybook and the researcher in order to observe aided AAC input, as they would for a modeled sign/gesture. Lastly, participants could request new aided AAC vocabulary, which may have been more motivating to communicate than vocabulary predetermined for both book-related signs/gestures and preprogrammed aided AAC hotspots. Thus, hotspots programmed just-in-time were expected to have a slight advantage over pre-programmed hotspots, as they may better reflect participant interests.

In line with study hypotheses, gestures were the predominant communication mode for all participants during baseline, with few to no concepts communicated via speech and none via participants' personal aided AAC systems (see Table **3-4** and Figures **3-4** and **3-5**). In fact, no participants communicated any book-related concepts using their personal AAC systems over the course of the study. During intervention, participants maintained relatively consistent low levels of speech production, decreased their rates of gestural communication slightly, and communicated a larger number of individual concepts using the VSD AAC system. Communication modality was also explored in relation to unique vocabulary concepts. Overwhelmingly, participants communicated the most unique vocabulary concepts using VSD AAC hotspots compared to other modes, followed by signs/gestures, and a small number of speech/speech approximations (see Table **3-5**). Vocabulary communicated via VSD AAC represented about an equal percentage of pre-programmed concepts and those only available in the AAC system as a result of just-in-time programming for all but one participant. Ian immediately began using most of the available pre-programmed hotspots to communicate upon transitioning into intervention. He also had just over half the total number of intervention sessions as other study participants, allowing him less opportunity to indicate an interest in programming and use of new hotspots. Thus, his percentage of total expressive aided AAC vocabulary that was programmed just-in-time was substantially smaller (17%) than the other study participants (35-55%).

Table **3-4**: Average number of individual symbolic concepts communicated per 10-minute session by modality in each study phase.

Participant	**Communication modality**								
	Baseline			Intervention			Maintenance		
	Speech	Gesture	Aided AAC	Speech	Gesture	Aided AAC	Speech	Gesture	Aided AAC
Henry	0	0.6	0	0.5	0.2	8.2	0	0.3	15
Lila	0.9	5.9	0	0.4	0.8	12.8	0.3	1.7	9.3
Lucas	0.3	1.4	0	0	0.9	19.3	1	2	39.5
Owen	0	5	0	0.8	3.5	4	–	–	–
Teagan	1	3.4	0	1	3.4	8.6	–	–	–
Ian	0.5	0.25	0	0.1	0	41.9	–	–	–

Note. No relevant, symbolic concepts were expressed by any participants during the study via their personal AAC system.

Table **3-5**: Total number of unique vocabulary concepts expressed by modality per participant across all study phases.

Participant	**Speech**	**Signs/gestures**	**Aided AAC**	**JIT***
Henry	2	4	27	52%
Lila	7	17	50	54%
Lucas	1	9	17	35%
Owen	3	4	18	39%
Teagan	7	6	11	55%
Ian	2	2	35	17%
Mean	3.7	7	26.3	42%

Note. A unique vocabulary concept communicated using more than one modality (e.g., gestures and aided AAC) was counted under both modes.
*JIT = percent of total aided AAC vocabulary only available as hotspots added just-in-time in response to participant interests

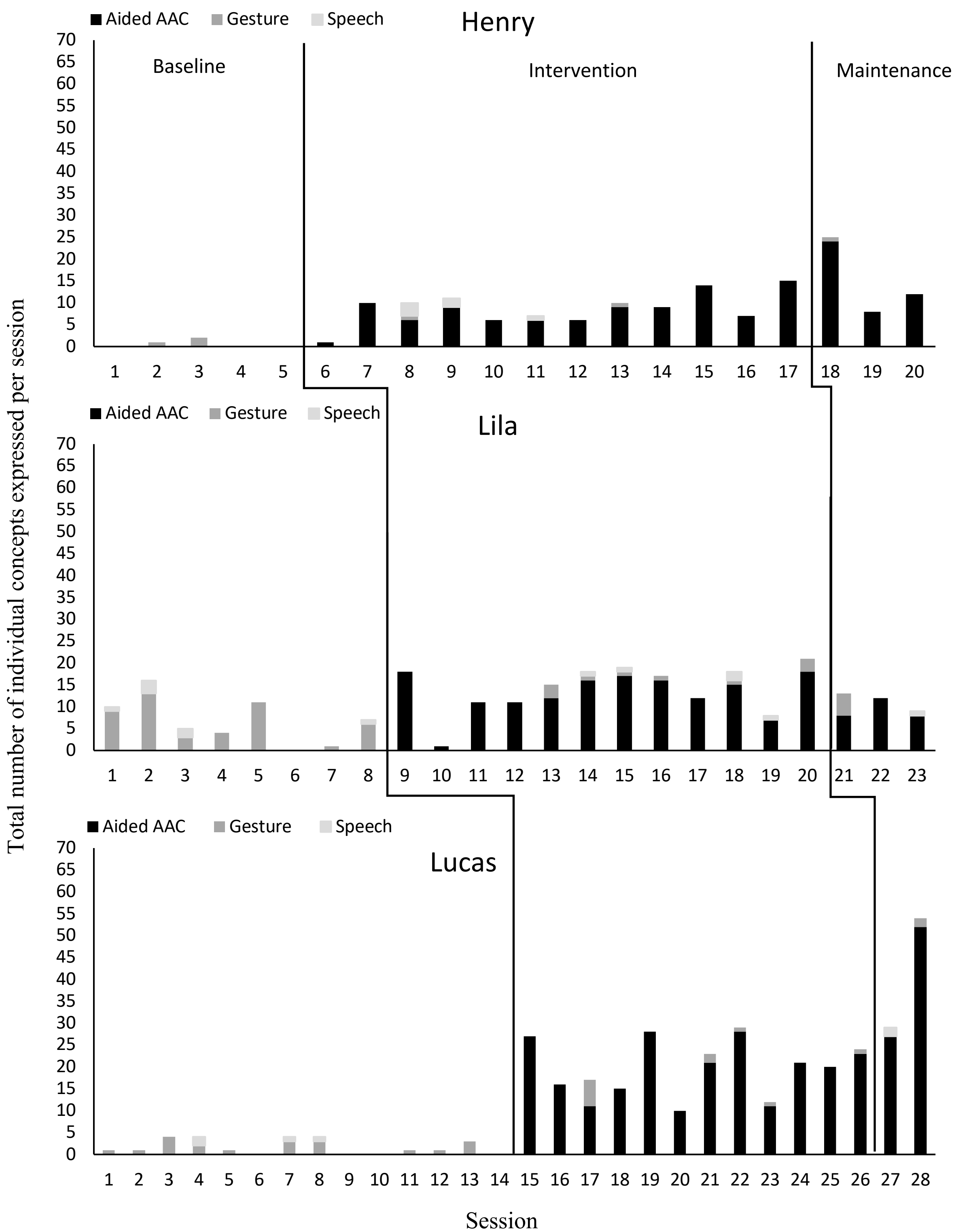

Figure **3-5**: Communication modality of each concept expressed per session across phases (leg 1; concurrent baseline).

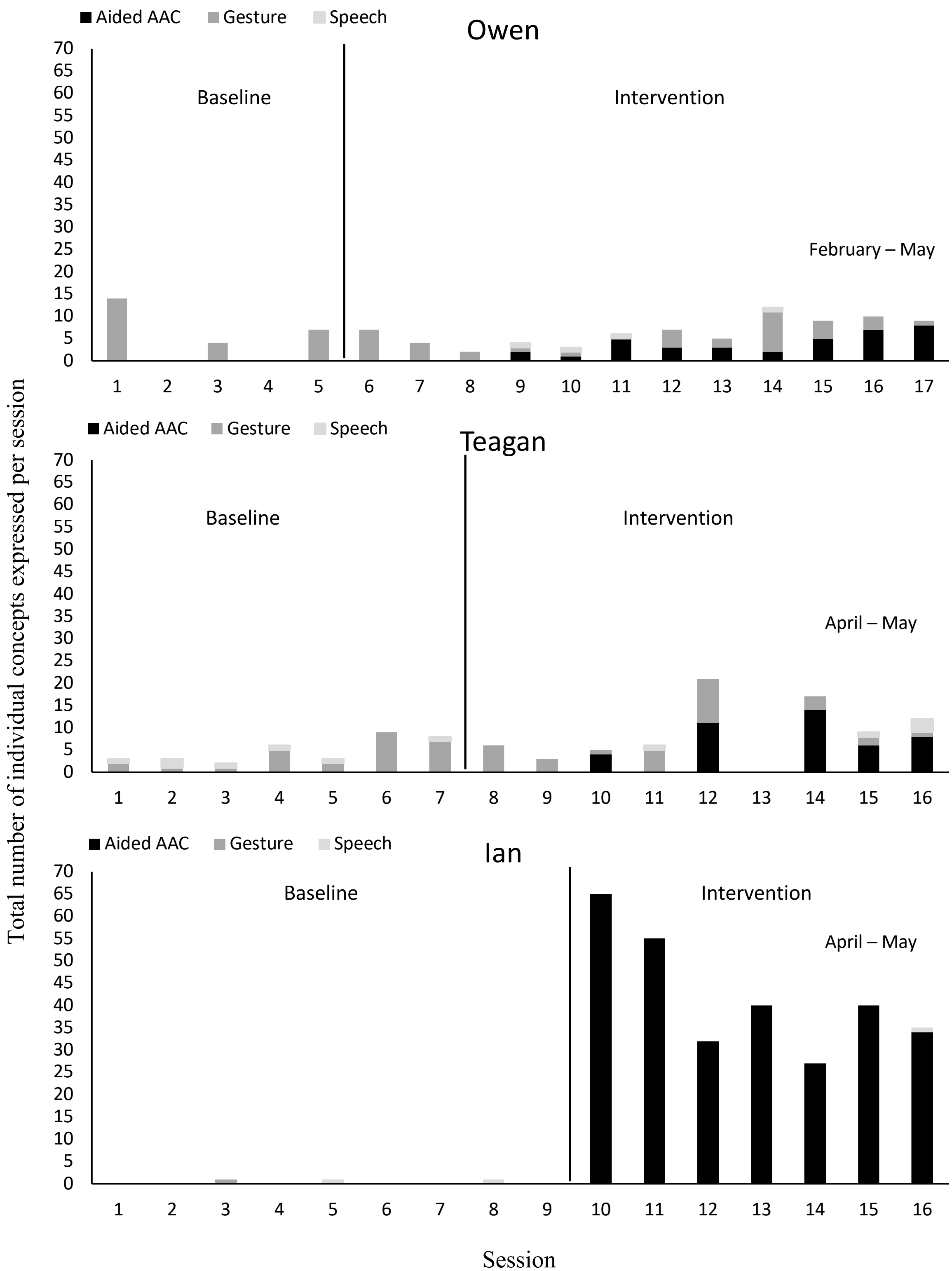

Figure **3-6**: Communication modality of each concept expressed per session across phases (leg 2; nonconcurrent baseline).

Henry

In baseline, Henry communicated infrequently and used exclusively gestures modeled by the researcher for symbolic communication (see Table **3-4** and Figure **3-4**). During intervention, he continued to use some gestural communication. Henry's most frequent communication modality during intervention was aided AAC output from the VSD hotpots, with an average AAC communication rate of 8.2 concepts per 10-minute session. The aided AAC vocabulary he communicated was balanced evenly between pre-programmed hotspots and hotspots programmed just-in-time in response to Henry's interests (52% of his concepts expressed via aided AAC were programmed just-in-time – see Table **3-5**). He also started incorporating speech approximations occasionally during shared storybook reading sessions during intervention. However, his average communication rate for speech and gestures combined was less than one concept communicated per session in either baseline or intervention. In the maintenance phase, Henry continued to communicate predominantly using the VSD AAC system, with an average of 15 concepts communication using aided AAC per maintenance session.

Lila

Lila used an average of 5.9 gestures per session in baseline (see Table **3-4**). She also used a small number of speech approximations (Figure **3-4)** but communicated less than one concept via speech per 10-minute session in either baseline or intervention. Lila's most frequent communication modality during intervention was AAC output from the VSD hotpots, with an average aided AAC communication rate of 12.8 concepts per 10-minute session. During maintenance, Lila maintained aided AAC as her most common communication mode (9.3 concepts communicated via aided AAC per session), but also continue to use a small corpus of gestures and speech approximations. The aided AAC vocabulary she communicated was also balanced relatively evenly between pre-programmed hotspots and hotspots programmed just-in-time in response to Lila's interests (54% of her concepts expressed via aided AAC were programmed just-in-time – see Table **3-5**).

Overall, Lila made notable progress in her unaided communication over the course of her participation in the study across contexts (e.g., school, home, within study procedures), as observed by the researcher and reported by her teacher and parents. She started using more spontaneous speech and signs, would nod/shake her head for yes and no, began to combine words via speech and sign, and also started to combine hotspots into 2-word combinations during study sessions. This rapid growth in overall communication may have been attributable at least in part to the resolution of her otitis media just before the study began, which allowed Lila to more readily hear and interact with her communication partners and the environment. However, both the timing of the resolution of Lila's otitis media prior to study initiation, as well as the downward trend in communicative turns observed in baseline suggest that the positive gains in storybook-related communicative turns during intervention are not simply a result of this overall growth in expressive communication.

Lucas

In baseline, Lucas communicated infrequently. He used predominantly book-related gestures modeled by the researcher to communicate, with the occasional addition of a few speech approximations (see Figure **3-4**). However, his frequency of speech production was very minimal – less than 0.5 concepts per 10-minute session across both baseline and intervention (see Table **3-4**). Lucas's most frequent communication modality during intervention was AAC output from the VSD hotpots, with an average aided AAC communication rate of 19.3 concepts per session. His use of aided AAC increased in maintenance, with an average of 39.5 concepts expressed using aided AAC per session in maintenance. His use of both speech and gestures to communicate also rose in the maintenance phase, with increases in both modes compared to either baseline or intervention. The aided AAC vocabulary Lucas communicated was comprised of a slightly greater representation of pre-programmed hotspots than hotspots programmed just-in-time in response to Lucas's interests (65% were preprogrammed and 35% of his concepts expressed via aided AAC were programmed just-in-time – see Table **3-5**).

Owen

Owen used gestures to communicate a modest number of times across baseline, with an average of five per 10-minute session (see Table **3-4**). However, Owen communicated only one unique vocabulary concept repeatedly in baseline (ring). During intervention, Owen continued to use gestural communication, but also began to incorporate aided AAC and occasional speech approximations starting in the fourth intervention session (see Figure **3-5**). Not coincidentally, this session is also when Owen began to show an upward trend in his number of symbolic turns, as well as an increasing slope in his number of unique concepts expressed. He continued to use all three communication modes throughout intervention, with gestures and aided AAC serving as relatively equivalent modalities of expression (see Table **3-4** and Figure **3-5**). However, Owen communicated a wider array of unique concepts via aided AAC than gestures (see Table **3-5**). Owen also used both preprogrammed hotspot vocabulary as well as vocabulary programmed just-in-time in response to his interests, but with a slight advantage for preprogrammed vocabulary (61% were preprogrammed and 39% of his concepts expressed via aided AAC were programmed just-in-time – see Table **3-5**).

Teagan

At the beginning of baseline, Teagan used a similar number of speech approximations and gestures, though both at low levels (see Figure **3-5**). Near the end of baseline and the beginning of intervention, Teagan communicated more frequently using gestures, in large part as a result of her frequent use of the "sleep" gesture. She began to incorporate aided AAC in the third intervention session, and she demonstrated a higher rate of aided AAC use vs. gestures or speech at the end of intervention. Overall, her rates of speech and gestural communication remained stable from baseline to intervention. The aided AAC vocabulary Teagan communicated was also balanced between concepts programmed just-in-time in response to her interests and preprogrammed aided AAC vocabulary (55% of her concepts expressed via aided AAC were programmed just-in-time – see Table **3-5**).

Ian

Ian communicated only four different concepts symbolically during baseline. In intervention, he demonstrated immediate uptake of the aided AAC system, communicating an average of 41.9 individual concepts each 10-minute session. His breadth of vocabulary also rapidly increased, with Ian adding 8-10 new concepts in each of the first two intervention sessions. Ian's speech and gestural communication remained at the same low level over the course of intervention. The aided AAC vocabulary Ian communicated was skewed strongly towards preprogrammed concepts vs. vocabulary programmed just-in-time in response to his interests, potentially as a result of his very high initial communication frequency using the already available hotspots, as well as his significantly shorter intervention phase (7 sessions as opposed to 12) providing less opportunities to demonstrate an interest in and use vocabulary programmed just-in-time (17% of his concepts expressed via aided AAC were programmed just-in-time – see Table **3-5**).

Highest frequency expressive vocabulary

The study also explored the characteristics of the participants' most frequently used expressive vocabulary concepts. These were the ten concepts communicated most often by each participant over the course of all baseline and intervention sessions, consolidated across all communication modalities. Maintenance data were excluded from frequency counts for this variable. It was hypothesized that participants would communicate noun concepts most frequently, with perhaps a few verbs and interjections (e.g., "oh no!" "whee!") sprinkled in, as nouns are most prevalent in the early vocabularies of young children who are initially developing language (McDonough et al., 2011). It was also anticipated that there would be a high proportion of vocabulary programmed just-in-time, as these concepts may better reflect participant interests than vocabulary pre-selected to target by the researcher.

As hypothesized, nouns were most frequently represented within the highest-frequency vocabulary concepts for most participants (see Table **3-5**). Specifically, participants often communicated the names of favorite book characters (e.g., Elmo, Cookie Monster, Daniel Tiger). However, the most frequently expressed concept across five out of six participants was either an interjection ("oh no!" or "whee!") or a verb ("ring" or "sleep"). Ian's most frequently communicated concept was "door," though his next-most-frequent concept was also a verb ("bite"). Verbs also had a high representation in participants' highest frequency vocabulary generally, trailing nouns by only a slight margin for most participants and exceeding the number of nouns for one participant (Lila).

Most participants communicated all ten of their most frequently expressed vocabulary concepts via VSD AAC (Owen and Teagen communicated 90% and 70% via aided AAC, respectively). However, all participants used more than one communication mode across their ten most frequently expressed concepts, and often communicated the same concept via multiple modes. Participants also communicated about a third to a little over half of the concepts using gestures, with the exclusion of Ian, who only communicated one high frequency concept using a gesture/action ("bite"). All participants but Ian also used speech to communicate at least one of their most frequently expressed vocabulary concepts, though most for only one concept. Vocabulary programmed into hotspots just-in-time in response to participant interests was present in the top ten most frequent concepts for all participants. However, there was notable variation across participants. Over half of Henry's most frequent vocabulary consisted of hotspots programmed just-in-time, while only one of Lila's most frequently communicated concepts was programmed just-in-time.

Table **3-6**: Highest frequency expressive vocabulary across baseline and intervention.

	Henry	Lila	Lucas	Owen	Teagan	Ian	
	Oh no[1,2,3]	Oh no[2,3]	Whee[2,3]	Ring (bell)[2,3†]	Sleep[1,2,3†]	Door[3*]	
	Cookie Monster[3]	Cookie Monster[1,3]	Oh no[2,3]	Siren[2,3†]	Elmo[3*]	Bite[2,3†]	
	Elmo[3*]	All gone[3*]	Sleep[1,2,3†]	Firehouse[3†]	Pajamas[3†]	Cake[3†]	
	Bert[3*]	Daniel Tiger[3]	Elmo[3*]	School bus[3†]	Grover[3*]	Cookie Monster[3]	
	Sleep[3†]	Snuggle[2,3†]	Baby David[3*]	Firetruck[3*]	Brush (teeth)[2]	Daniel Tiger[3]	
	Ernie[3*]	Bite[2,3†]	Pajamas[3†]	Elmo[3*]	Cookie Monster[3]	Cookies[3]	
	Grover[3*]	Open[2,3†]	Snuggle[2,3†]	Blanket[3]	Door[1]	Open[3†]	
	Ring (bell) [2,3†]	Present[3†]	Brush (teeth)[2,3]	Whee[1,2]	Snuggle[1,2†]	Oven[3]	
	Zoe[3*]	Sleep[2,3†]	Swings[3†]	Sleep[3†]	Bite[3†]	Mix[3]	
	Brush (teeth)[2,3]	Mix[2,3]	Grover[3*]	Big Bird[3*]	Ernie[3*]	Bus[3*]	
Part of speech							**Total**
Nouns	6 (60%)	3 (30%)	5 (50%)	7 (70%)	6 (60%)	7 (70%)	34
Verbs	3 (30%)	5 (50%)	3 (30%)	2 (20%)	4 (40%)	3 (30%)	20
Interjections	1 (10%)	1 (10%)	2 (20%)	1 (10%)	0 (0%)	0 (0%)	5
Descriptors	0 (0%)	1 (10%)	0 (0%)	0	0 (0%)	0 (0%)	1
Modality							
Speech	1 (10%)	1 (10%)	1 (10%)	1 (10%)	3 (30%)	0 (0%)	7
Gestures	3 (30%)	6 (60%)	5 (50%)	3 (30%)	3 (30%)	1 (10%)	21
Aided AAC	10 (100%)	10 (100%)	10 (100%)	9 (90%)	7 (70%)	10 (100%)	56

Note: Vocabulary are listed in order of communication frequency by the participant over the course of baseline and intervention.

[1] Communicated via speech (at least once)

[2] Communicated via gestures (at least once)

[3] Communicated via aided AAC (at least once)

* Vocabulary programmed just-in-time

† Vocabulary targeted within the main receptive language measure

Henry

Henry's most frequently communicated concept was "oh no!" Six of his ten concepts were Sesame Street character names, all but one of which (Cookie Monster) were programmed just-in-time. The remaining three concepts in Henry's top ten were verbs that had been both pre-programmed as hotspots prior to intervention and also modeled as signs/gestures throughout the study. Overall, Henry's most frequent vocabulary included six nouns, three verbs, and one interjection, and five of those concepts were programmed as hotspots just-in-time. Henry communicated all of his most frequent vocabulary concepts via VSD AAC. He also communicated three of those concepts using gestures (all of which were modeled book-related signs/gestures), and one also via speech.

Lila

Lila's most frequently communicated concept was also "oh no!" Both Lila and Henry's second-most frequent vocabulary concept was "Cookie Monster." Lila had the greatest representation of verbs (five), all of which were both pre-programmed as hotspots and modeled as signs/gestures. Her remaining most frequent vocabulary items included three nouns (two of which were book characters), one interjection, and one descriptor. Interestingly, the only vocabulary programmed just-in-time as a hotspot that made her top ten was the single descriptor ("all gone"). Lila communicated all ten of her most frequent vocabulary concepts using VSD AAC. She also expressed over half (60%) using signs/gestures – all of which were modeled by the researcher. She only communicated one of her most frequent vocabulary concepts via speech.

Lucas

Lucas's most frequently communicated concept was a different interjection ("whee!"). His second-most frequent vocabulary concept was another interjection ("oh no!"). Lucas had a similar proportion of nouns and verbs as Henry, with five nouns, three verbs, and two interjections. Three of Lucas's most frequently communicated nouns were also Sesame Street characters, all of which were programmed as hotspots just-in-time. All other concepts in Lucas's top ten were either pre-programmed hotspots, modeled signs/gestures, or both. Lucas communicated all of his most frequent vocabulary concepts via VSD AAC. He also expressed half of these concepts using signs/gestures – all of which were modeled by the researcher – and one of his most frequent vocabulary concepts also via speech.

Owen

Owen's most frequently communicated concept was a verb ("ring"), in large part as a result of his frequent sign approximations for this concept throughout the study. Owen's most frequent vocabulary had a large proportion of nouns (seven), in addition to two verbs and one interjection. A third of his ten vocabulary concepts were programmed just-in-time. Owen communicated nine of his most frequent vocabulary concepts using VSD AAC, three using gestures, and only one via speech.

Teagan

Teagan's most frequently communicated concept was also a verb ("sleep") and was similarly a frequent gesture approximation in her lexicon during shared storybook reading sessions. Six of her ten concepts were nouns, four of which were Sesame Street characters – three of which were programmed just-in-time in response to Teagan's interests. The remaining four concepts in Teagan's top ten were verbs that had been both pre-programmed as hotspots during intervention and also modeled as signs/gestures throughout the study. Teagan communicated seven of her most frequent vocabulary concepts via VSD AAC, and three each via gestures and/or speech.

Ian

Ian's most frequently communicated concept was a noun ("door"). However, his second-most frequent vocabulary concept was a verb ("bite"). Ian had a similar proportion of nouns and verbs as Teagan, with seven nouns and three verbs. Only two of Ian's most frequently communicated concepts were programmed just-in-time in response to his interests. Ian communicated all ten of his highest frequency vocabulary using VSD AAC, one also via gestures, and none using speech.

Vocabulary programmed just-in-time

Analyses also considered the characteristics of vocabulary programmed just-in-time as hotspots within the VSD system, in response to participant interest. It was hypothesized that vocabulary would predominantly consist of nouns, as nouns make up the largest proportion of the early expressive vocabularies of young children who are initially developing language (McDonough et al., 2011). In addition, some degree of interpretation based upon the context and child behavior is often necessary on the part of a communication partner to determine what specific speech output should be programmed for a hotspot added just-in-time, especially when the child's interest is not accompanied by intelligible speech and/or symbolic gestures. Given the imageability of nouns within the book illustrations, it was most likely for the researcher to be primed to interpret participant interests (most often communicated by the participant touching a part of the book page) as referring to nouns. Participants did occasionally appear to protest the researcher's interpretation of the vocabulary to be programmed (e.g., shaking head "no," navigating to a different book page, touching the button to cancel programming), though this was infrequent. In these cases, the researcher presented a different (relevant) potential vocabulary concept for speech output, and this alternate concept was programmed (if not protested).

The number of different vocabulary concepts programmed just-in-time across intervention and maintenance varied significantly across participants (see Table **3-7**). A total of 48 unique concepts were programmed just-in-time for Lila, increasing to 96 when repeated programming of the same vocabulary concept was included. By contrast, only 11 total vocabulary concepts were programmed by the researcher just-in-time in response to Lucas's interests. Lila's relatively robust repertoire of vocabulary programmed just-in-time is likely related in large part to her quick independent learning of the operational vocabulary programming steps. All but one participant (Teagan) had at least one hotspot programmed just-in-time during the first intervention session, in response to their interests (i.e., as a result of a participant communication attempt that indicated a concept not already available as a hotspot on that storybook page). However, two participants (Lucas and Teagan) appeared to take longer than the other four participants to catch on to the process of indicating interest in adding new hotspot vocabulary within the aided AAC system. This delay in just-in-time hotspot vocabulary programming potentially contributed to the variation across participants in the total number of vocabulary concepts programmed just-in-time during intervention and maintenance. All but one participant (Owen) used around one half to two thirds of their vocabulary programmed just-in-time expressively (see Table **3-7**) – either in the same session that the concept was programmed and/or in future sessions. Owen communicated 31% of his just-in-time programmed vocabulary concepts.

In line with the study hypothesis, almost all vocabulary programmed just-in-time consisted of nouns – though verbs, descriptors, and interjections were all represented to some degree (see Table **3-7**). Within programmed nouns, book characters were the most represented noun class. Interestingly, all participants indicated an interest in at least one vocabulary concept being programmed just-in-time multiple times, whether on the same book page or on another page containing the same concept. However, this pattern was also dependent upon the researcher's interpretation of participants' specific intentions.

Just-in-time programming also allowed for an unanticipated outcome in participant communication and language. All participants communicated at least one two-word combination using two hotspots on the same storybook page by selecting the hotspots in immediate succession (see Table **3-3** and Appendix K). As only one concept was preprogrammed on each storybook page, two-word aided AAC utterances were dependent upon participants showing an interest in adding additional vocabulary just-in-time within the storybooks.

Henry

A total of 23 unique concepts were programmed just-in-time in response to Henry's interests during shared storybook reading sessions in intervention and maintenance. The vocabulary added just-in-time consisted almost entirely of nouns (as interpreted by the researcher), with only one verb represented (see Table **3-7**). Almost half of his vocabulary programmed just-in-time was made up by book characters.

Over the course of intervention and maintenance, Henry expressively communicated 61% of the vocabulary programmed just-in-time via aided AAC. Henry had six concepts that he requested to be programmed more than once, four of which were storybook characters.

Lila

There was slightly more diversity in the parts of speech represented in the vocabulary programmed just-in-time in response to Lila's interests, potentially as a result of her relatively high rate and diversity of gestural communication, which provided additional clues to the nature of her interests. However, the vast majority of vocabulary programmed just-in-time for Lila also consisted of nouns, though only about a quarter of those nouns were book characters (see Table **3-7**). Across all participants, Lila also had the largest number of different concepts programmed just-in-time (48), as well as the highest frequency of repeated programming of the same concept. Lila would often indicate interest in programming the same concept across multiple pages (e.g., "Cookie Monster" on all of the storybook pages in which he appeared within a book) or reprogramming the same hotspot on top of a preexisting one the next session (e.g., programming a hotspot for "Cookie Monster" on the first page, on top of the already-available "Cookie Monster" hotspot).

Lila's high rate of repeated programming and reprogramming was related in large part to the fact that she was also the only participant to quickly learn and consistently engage in all of the steps of creating new hotspots (entirely of her own volition): selecting the hotspot button, drawing a hotspot on the book page, and recording audio (vocalizing at the appropriate time). Thus, she had the most agency in decided when and where to program new hotspots (or reprogram the same ones). Over the course of intervention and maintenance, Lila expressively communicated 65% of the vocabulary programmed just-in-time via aided AAC.

Table **3-7**: All vocabulary programmed as hotspots just-in-time in response to participant interests (intervention and maintenance).

Participant	Vocabulary programmed just-in-time	Nouns	Verbs	Interjections	Descriptors	Total		Programmed per session (rate)	% Used expressively
Henry	**Abby**, Baby David, **Bert**, **Big Bird**, **bite**, **book**, cabinet, cake, **Cookie Monster** (3), cookies, **Elmo** (2), **Ernie** (2), firefighter (3), firehouse, firetruck (2), **Grover** (2), **Pete the Cat** (2), pillow, **school bus**, sheep, **teeth**, **The Count**, **toothbrushes**	22	1	0	0	23		1.9	61%
Lila	**All gone**, backpack, **baker** (4), **baking** (4), bed, **Bert**, **Big Bird** (2), **birthday**, **bite** (2), Bob, **bowl** (3), box, **bubbles**, **cake** (3), **candies**, **chocolate chips** (2), cocoa, **Cookie Monster** (7), cookie sheet, **cookies** (2), **Daniel Tiger** (3), **decorating**, doll, **door** (2), **eggs** (3), **Elmo** (5), Ernie (4), Grover, handle, **hat** (8), hot, house, **icing**, ingredients, legs, **milk** (3), **oh no** (3), **Pete the Cat** (4), **presents**, **shapes**, shoes, snow, spoon (2), **sprinkles**, **star**, **The Count**, **triangle**, **white chocolate chips**	42	3	1	2	48		4	65%
Lucas	**Abby**, **Baby David**, Big Bird, The Count, circle, cookies, **doll**, **Elmo**, **Grover**, **oh no** (2), **swings**	10	0	1	0	11		0.9	64%
Owen	Abby, **Big Bird**, backhoe, **blanket**, boot, bubbles, **Cookie Monster**, cookies, The Count, doll, eat, **Elmo**, **firefighter** (2), **firetruck** (5), **fire jacket**, **flames**, Grover, Grumpy Toad, guitar, hose, Pete the Cat (2), pipes, sandbox, slide, teddy bear, Zoe	25	1	0	0	26		2.2	31%
Teagan	Baby David**, Bert** (2), **Big Bird**, **bite** (2), **Cookie Monster** (4), The Count, door (2), **Elmo** (2), **Grover** (2), **hello**, milk, wand, yum, Zoe	11	1	2	0	14		1.2	50%
Ian	**Big Bird, bite** (3)**, boots, bowl** (2), **bus**, **cake** (3), candies, **Cookie Monster** (3)**, Daniel Tiger, door** (3)**,** eat, Elmo, friends, **fire jacket**, **Grover, mix, oh no, open, presents, Prince Wednesday**, sandbox, sprinkles, toaster	18	4	1	0	23		3.3	70%
	Total	128	10	5	2	145	**Mean**	2.4	57%

Note. Just-in-time hotspot vocabulary items in **bold** were used expressively via aided AAC by the participant during 10-minute video coding excerpts from study sessions. Note that additional vocabulary may have been requested to be programmed and/or used expressively during study sessions outside of the 10-minute coding excerpts.

Lucas

A total of 11 unique concepts were programmed just-in-time in response to Lucas's interests during intervention and maintenance. Lucas's hotspot vocabulary programmed just-in-time was also almost entirely nouns, with only one exclamation included ("oh no!"; see Table **3-7**). This was also the only vocabulary concept Lucas indicated interest in having programmed more than once. Similar to Henry, six out of the eleven total hotspots programmed just-in-time for Lucas were book characters. Over the course of intervention and maintenance, Lucas expressively communicated 64% of the vocabulary programmed just-in-time via aided AAC.

Owen

A total of 26 unique concepts were programmed just-in-time in response to Owen's interests (see Table **3-7**). Owen indicated interest in having three concepts programmed more than once (i.e., firefighter, firetruck, Pete the Cat). He demonstrated a similar pattern of interest in noun concepts for just-in-time programming, with only one verb ("eat"). Nine of the vocabulary concepts programmed just-in-time were book characters. Over the course of intervention and maintenance, Owen expressively communicated 31% of the vocabulary programmed just-in-time via aided AAC. Given Owen's relative challenges with isolating a point, the researcher had more difficulty recognizing and responding appropriately to his communication attempts (e.g., indicating a concept on the storybook page). Thus, it is possible that some of the vocabulary programmed just-in-time may not have represented the concepts that he was motivated to communicate.

Teagan

A total of 14 unique concepts were programmed just-in-time in response to Teagan's interests during intervention. Teagan was the only participant who did not indicate interest in a concept that resulted in just-in-time programming during the first intervention session. Her first just-in-time hotspots were added in the third intervention session. Teagan's vocabulary programmed just-in-time was predominantly nouns, with one verb ("bite") and two exclamations ("hello" and "yum"; see Table **3-7**). Five concepts were programmed multiple times over the course of the study. Teagan also had a high proportion of book characters in her set of vocabulary programmed just-in-time (8 out of 14). Over the course of intervention, Teagan expressively communicated 50% of the vocabulary programmed just-in-time via aided AAC.

Ian

A total of 23 unique concepts were programmed just-in-time in response to Ian's interests during intervention. His vocabulary programmed just-in-time followed the same pattern as the other participants, with predominantly nouns, four verbs, and one exclamation ("oh no!"; see Table **3-7**). He indicated five concepts for repeated programming. Over the course of intervention, Ian expressively communicated 70% of his vocabulary programmed just-in-time via aided AAC.

Comprehension of spoken words

Participants' comprehension of book-related spoken words was assessed at multiple timepoints over the course of the study. The main spoken word comprehension measure was completed three times: prior to baseline, between baseline and intervention, and following the completion of intervention. The pre-baseline assessment was a measure of participants' comprehension of the spoken label for pre-determined book-related concepts prior to study participation. The post-baseline measure served as a way to capture any growth in participants' comprehension of the spoken words associated with the targeted concepts over the course of baseline sessions with NDBI procedures. The post-intervention assessment served as a measure of any additional learning of target concept vocabulary spoken words with the addition of VSD AAC, just-in-time programming, and aided AAC input into NDBI procedures. This task was intended to provide an approximate index of participant comprehension of spoken words and learning of targeted vocabulary over the course of the study; however, a lack of experimental control and the cumulative nature of the probes limits the strength of the conclusions that can be drawn from these results.

It was hypothesized that participants would experience a moderate increase in their performance on the spoken word comprehension measure from pre- to post-baseline, but a larger increase in performance by the end of intervention. NDBI procedures without aided AAC have shown a small effect on language comprehension (Pope et al., 2023; Sandbank et al., 2020; Tiede & Walton, 2019). However, evidence indicates that general AAC intervention that includes aided AAC input as a component has a large effect on comprehension (O'Neill et al., 2018). Thus, participants were expected to demonstrate greater growth in their comprehension of spoken words with the inclusion of VSD AAC and aided AAC input.

Contrary to study hypotheses, no significant positive change above chance levels (25%) was observed in percent accuracy on the main spoken language comprehension measure at either the end of baseline or intervention for any participant (see Table **3-7**). In fact, many participants demonstrated decreasing levels of accuracy over time, though this may also be attributable to chance, a lack of understanding of task expectations, or challenges with task compliance, given the low levels of performance overall. Many participants opted to read the same subset of 2-3 storybooks repeatedly across study sessions, choosing the remaining 2-3 books from their five-book set infrequently or never. Thus, they had little to no exposure to the target vocabulary concepts in the less preferred storybooks, which may have been a factor in overall low performance on the main comprehension measure of spoken words.

As a result, individualized spoken word comprehension measures were developed post-hoc, consisting of the ten highest frequency vocabulary communicated expressively by each participant in baseline and intervention (see Table **3-5**), using the same format as the original main comprehension measure of spoken words. The individualized post-hoc spoken word comprehension measure had two parts: (1) one section with the high frequency vocabulary represented using pictures from the book illustrations used in the study, and (2) one section with that same vocabulary represented using novel digital photographs, as a measure of generalization of the target concepts. The goal of including this measure was to investigate whether participants demonstrated comprehension of the spoken words associated with their most frequently expressed vocabulary concepts. Due to scheduling constraints, Ian was unavailable to participate in either the individualized post-hoc comprehension measure of spoken words or the final post-intervention probe of the main spoken word comprehension measure.

Half of the participants demonstrated higher levels of accuracy identifying book-related vocabulary from the spoken word for those concepts that they had used expressively on multiple occasions, in comparison to the pre-established vocabulary targeted in the original comprehension measure of spoken language (see Table **3-7**). One participant (Henry) was also more successful identifying his highest-frequency expressive vocabulary concepts from the spoken word when represented using digital photographs than his performance in the main comprehension measure. However, Owen and Teagan continued to consistently perform at chance levels across all spoken word comprehension measures over the course of the study, including both the pre-established main comprehension measure and the individualized post-hoc measure of spoken words.

Table **3-8**: Percent accuracy identifying the spoken word for targeted storybook-related language concepts.

Participant	**Main comprehension measure of spoken words** (pre-established)			**Individualized comprehension measure of spoken words** (post-hoc)	
	Pre-baseline	Post-baseline	Post-intervention	Book illustrations	Digital photographs
Henry	35%	25%	30%	70%	50%
Lila	30%	25%	25%	50%	30%
Lucas	45%	30%	30%	50%	40%
Owen	20%	5%	35%	10%	30%
Teagan	10%	25%	20%	20%	30%
Ian	20%	35%	–	–	–

Note. Vocabulary included in the individualized post-hoc comprehension measure of spoken words reflects the ten most frequently communicated concepts across baseline and intervention, per participant.

Caregiver social validity

Caregivers for four of the participating children completed a social validity activity to gather their perceptions of the value of the study. Two of these caregivers were present at home when intervention sessions occurred, though were typically engaged in other tasks. Due to scheduling constraints, both Owen and Ian's caregivers were unavailable to participate. Following the end of intervention, each caregiver watched two separate, randomly selected, five-minute video clips of their participating child (one clip from intervention, and one clip from baseline) and completed a short questionnaire. Responses from caregiver social validity questionnaires can be found in Table **3-9**.

Overall, caregivers rated the intervention procedures more positively than baseline procedures in supporting their child's communication, participation, and enjoyment, and were more likely to indicate that they would recommend the activity to others. However, Teagan's caregiver rated the video clips of her participating child from baseline and intervention equally across all questions. This aligns with study results, as Teagan experienced the smallest gains in her number of communicative turns from baseline to intervention. Additionally, the baseline video clip randomly selected for the social validity activity was one in which Teagan and the researcher engaged in a substantial number of nonsymbolic communicative interactions (i.e., Teagan touching the researcher's face to request the researcher do the "sleep" gesture).

In general, there was greater variability in caregiver perspectives for baseline NDBI procedures, with some caregivers disagreeing or even strongly disagreeing with the activity's effectiveness in supporting communication and participation for their child, with other caregiver perspectives ranging from neither agree nor disagree to strongly agree. Henry's and Lucas's caregivers provided the least positive ratings of the baseline activity. These two participants also communicated the least frequently during baseline of the four participants whose caregivers participated in the social validity activity. Thus, it is unsurprising that they would view the baseline procedures as generally unsupportive of their participating child's communication, participation, and enjoyment.

By contrast, all caregivers agreed or strongly agreed regarding the positive impact of intervention procedures with the addition of aided AAC with VSDs and digitized speech output, just-in-time programming, and aided AAC input on the communication, participation, feasibility, enjoyment, and likelihood of a positive recommendation to others. During natural language sample storybook reading sessions with caregivers prior to baseline, participants took few to no communicative turns, and remained engaged for a shorter duration of time than during intervention sessions. This may account in large part to the very positive caregiver perceptions of the intervention. Importantly, all caregivers strongly agreed that both baseline and intervention procedures seemed feasible for a parent or teacher to complete with the child, suggesting that the addition of the aided AAC component (along with just-in-time programming and aided AAC input) into NDBI strategies during intervention did not make the intervention seem more intimidating for a caregiver or teacher to implement.

Three forced-choice questions asked caregivers to rate which video of their child showed more effective communication, more active participation, and greater enjoyment of the activity. All caregivers agreed that their children participated more actively and enjoyed the activity more during intervention. All but one caregiver also indicated that their child communicated more effectively during intervention, with access to VSD AAC, just-in-time programming, and aided AAC input. This outlier was also Teagan’s caregiver. Her positive perceptions of Teagan’s communication in the baseline social validity video clip may have also been related to Teagan’s relatively frequent nonsymbolic communicative exchanges with the researcher.

Table **3-9**: Results of caregiver social validity questionnaires.

NDBI strategies in shared storybook reading (Baseline)	Strongly disagree				Strongly agree
The activity was effective at supporting the participant's communication.	1	1		1	1
The participant could participate independently in the activity.	1	1	1		1
The activity seems feasible for a parent or teacher to do with the participant.				1	3
The participant seemed to enjoy the activity.		1	2	1	
I would recommend this activity to others.			1	2	1
NDBI strategies + VSD AAC, just-in-time programming, and aided AAC input in shared storybook reading (Intervention)	Strongly Disagree				Strongly Agree
The activity was effective at supporting the participant's communication.				1	3
The participant could participate independently in the activity.				1	3
The activity seems feasible for a parent or teacher to do with the participant.				1	3
The participant seemed to enjoy the activity.				2	2
I would recommend this activity to others.				1	3

	NDBI strategies only (Baseline)	**NDBI + VSD AAC, just-in-time programming, and aided AAC input** (Intervention)
In which video did the participant communicate more effectively?	1 (25%)	3 (75%)
In which video did the participant participate more actively?		4 (100%)
In which video did the participant appear to enjoy the activity more?		4 (100%)

Chapter 4

Discussion

The current study is the first to explore the integration of VSD AAC technology with just-in-time programming and aided AAC input within an NDBI framework for young children on the autism spectrum with minimal speech. Study results indicate that this combination of developmentally appropriate AAC technology and NDBI techniques within a familiar, motivating context had positive effects on the number of communicative turns children took, the number of unique vocabulary concepts they expressed, and their influence over access to expressive vocabulary. All participating children even began to demonstrate generative language by combining concepts together spontaneously via aided AAC. Furthermore, these gains came with no negative impact on speech production.

These results demonstrate that the addition of VSD AAC with digitized speech output, just-in-time programming, and aided AAC input to NDBI procedures can support both social pragmatic (turn taking) and semantic (unique vocabulary concepts) development for young children on the autism spectrum with minimal speech – even supporting the emergence of early semantic relations. Positive changes in participant language and communication were observed with a low intensity (around 45 minutes a week) and after a very short duration (3 hours or less) of intervention, suggesting young children on the autism spectrum with minimal speech can benefit without imposing high demands on communication partners, professionals, or children themselves. Importantly, caregivers viewed the intervention procedures as both highly effective and feasible to implement themselves, indicating the positive potential for uptake across communication partners and contexts.

Additional analyses of participant communication further revealed trends regarding the type, mode, and underlying comprehension of the spoken word for the vocabulary participants programmed and used. Participants were most likely to both communicate and indicate an interest in adding new hotspots for noun concepts, though verbs and interjections were also highly preferred. The number of unique concepts programmed just-in-time in response to participant interests varied widely across participants (total number = 11 to 48; mean number per session = 0.9 – 4), though all participants both requested additional vocabulary and used a subset of this added vocabulary expressively. Taken together, these results have strong implications for AAC vocabulary selection. For beginning communicators on the autism spectrum with minimal speech, focusing on these types of concrete concepts in the vocabulary modelled and programmed into AAC systems may be the most supportive of language and communication development in the early stages (Laubscher & Light, 2020).

Aided AAC was the most common expressive communication modality once participants had access to the VSD AAC system during intervention, indicating the importance of providing access to developmentally appropriate and personalized aided AAC systems. However, all participants continued to communicate using gestures and speech throughout the study. In fact, during baseline, all participants started to use at least one modeled sign/gesture expressively and continued to use gestures symbolically during intervention. Although the results of this study demonstrate the powerful impact of VSD AAC on language and communication, this pattern indicates the importance of both modeling and acknowledging multimodal communication.

Results of comprehension probes suggests that participants did not demonstrate substantial measurable comprehension gains in learning the spoken words for targeted vocabulary over the course of the short intervention period. This may have been related in large part to a lack of consistent exposure to many of the predetermined target language concepts during study sessions. Additionally, these results do not exclude the possibility that participants may have understood the underlying concepts themselves but were unsure of the task expectations, had not yet paired those concepts to the spoken word, and/or struggled to match the spoken word to the visual representation when it was decontextualized from the larger scene. Most participants did demonstrate higher (though often still modest) accuracy identifying the individualized vocabulary that they communicated most often during study sessions within post-hoc comprehension probes. However, rates on the individualized spoken language comprehension measure remained modest, suggesting the possibility that participants may have also leveraged their access to a wider and growing array of expressive language via VSD AAC as a method of supporting their comprehension of spoken language – a pattern also observable in neurotypical children first learning language (Nelson, 1973).

Comparison to previous research

To date, minimal research has explored the integration of aided AAC into NDBI strategies – though the evidence that does exist is highly encouraging (e.g., Alrayzer et al., 2021; Kasari et al., 2014; Olive et al., 2007; Schepis et al., 1998 – see Pope et al., 2023 for a review). The extant NDBI AAC research typically compares intervention procedures that include both aided AAC and NDBI strategies to a baseline phase consisting of observations of participants in the natural environment, prior to introduction of NDBI strategies or aided AAC (e.g., Alrayzer et al., 2021; Johnston et al., 2003; Olive et al., 2007; Schepis et al., 1998). This limits the potential to distinguish between the relative contribution of NDBI strategies and the introduction of aided AAC in relation to gains in participant communication. Similarly, research that compares NDBI procedures to highly structured ABA interventions (e.g., discrete trial training – Schreibman & Stahmer, 2014; Yoder & Stone, 2006) offers some insight into the relative strengths of aided AAC and NDBIs. However, the stark difference in overall intervention procedures makes the causal factors attributable to any observed differences unclear. By contrast, the current study compared NDBI procedures alone to the integration of VSD AAC with digitized speech output, just-in-time programming, and aided AAC input into those same NDBI strategies. This design allowed for finer grained assessment of the relative contribution of NDBIs and aided AAC to language and communication growth in study participants – although it should be noted that the sequential nature of the study phases suggests the need for a degree of caution when considering strong causal interpretations regarding the relative contributions of each factor.

Only one previous study has specifically explored the *added* effect of incorporating aided AAC into NDBI procedures for young children on the autism spectrum with minimal speech, in comparison to

NDBI strategies alone (Kasari et al., 2014) – the goal of the current study. Similar to the current research, Kasari et al. (2014) focused on social communicative functions, as opposed to object requests. Kasari et al. (2014) compared the number of socially communicative utterances, comments, and unique expressive vocabulary of 61 children ages 5-7 on the autism spectrum with minimal speech, half of whom participated in a blended NDBI (JASP+EMT) only, while the other half also had access to high tech aided AAC within the same NDBI intervention (described only as a "speech generating device," though other presentations on this work suggest these were traditional grid-based AAC systems with picture symbols and preprogrammed vocabulary).

Results showed a significant positive impact on all communication variables when aided AAC was included within the intervention procedures. These benefits also extended to spoken language specifically, as participants with access to aided AAC increased their spoken language to a greater extent than those who did not. Critically, through strategic study design, Kasari et al. (2014) were able to demonstrate that participants who had access to aided AAC from the start of the intervention experienced significantly greater gains in their language and communication than participants who received aided AAC partway through the study procedures. Access to effective and appropriate AAC systems as early in development as possible is essential to maximize long-term language and communication outcomes.

Participants in Kasari et al. (2014) spent 48 total hours in intervention, at a higher intensity per week (two hours a week for 24 weeks) than the current study. By contrast, the current study consisted of approximately 3 total hours of intervention across four weeks. However, in that substantially shorter time, all participants in the current study were able to significantly increase their symbolic communication rate, as well as diversify their vocabulary. With just three total hours of intervention, participants communicated 11-42 additional words that they had not expressed during baseline. Within 12 weeks (24 total hours of intervention), participants in Kasari et al. (2014) increased their number of unique vocabulary items per session by 16 concepts. However, it should be noted that this measure reflected vocabulary used in a single session, whereas the current study measured vocabulary growth across all study sessions.

Additionally, participant age ranges between the two studies included children at very different stages in development (5-7 years old in Kasari et al., 2014 as compared to 3-5 years old in the current study). Participants in Kasari et al. (2014) were also reported to have more advanced expressive and receptive language skills than participants in the current study, using approximately 30 socially communicative utterances and 17 different unique vocabulary concepts via speech during a 10-minute language sample prior to study participation. By contrast, children in the current study took 0-2 communicative turns during 10-minute shared storybook reading interactions with their caregivers as a part of the natural language samples completed prior to study participation.

Previous research targeting children with developmental delays and minimal speech (but, importantly, excluding autism) has also showed similarly encouraging results regarding the incorporation of aided AAC as a critical intervention ingredient within naturalistic intervention designs (Romski et al., 2010). Romski et al. (2010) conducted a parent-mediated intervention comparing expressive language growth for 68 slightly younger children (2.5 years old), a third of whom were each randomly assigned to a speech-only, aided AAC input, or aided AAC output condition. Participants in both the aided AAC input and output conditions communicated a significantly greater number of unique vocabulary concepts by the end of the study than their contemporaries in the speech-only condition (Romski et al., 2010). Similar to the results from Kasari et al. (2014), this increase was even apparent when considering speech alone; the children with access to aided AAC started to use more spoken language than those without access to aided AAC.

Participants in Romski et al. (2010) were closer in age and communication profile to the participants in the current study – but again, participating children in Romski et al. (2010) were *not* on the autism spectrum, the focus of the current study. Weekly intervention intensity was also similar with two half-hour sessions a week, as compared to three 15-minute sessions in the current research. However, Romski et al. (2010) had a much longer duration than the current study, lasting for a total of 24 weeks (as compared to four weeks). Importantly, the interventionists in Romski et al. (2010) were parents trained in the intervention techniques, as opposed to the researchers themselves (as is the case in the current study). Additionally, the procedures of the current study combined components of the two aided AAC conditions in Romski et al. (2010). In the current study, the researcher provided aided AAC input (i.e., modeled selecting VSD hotspots in tandem with speech), along with a moderate level of prompting to encourage the participant to use the VSD AAC system expressively (i.e., expectant delay and gestural prompt to the VSD system generally). Participants in Romski et al., (2010) either experienced aided AAC input from their communication partners or direct prompting to support their expressive use of the AAC system (aided AAC output) – but not both. However, the aided AAC output condition in Romksi et al. (2010) included more direct verbal and physical prompting to encourage the participating children to use the aided AAC system expressively, which was not included in the current study procedures.

Over the course of 24 total intervention hours, participants in Romski et al. (2010) communicated an average of 16-19 different concepts after 18 hours of intervention, with no additional vocabulary growth by the end of the study at 24 intervention hours. In the current study, participants communicated 10-42 additional words that they had not expressed during baseline over the course of approximately three total hours of intervention over a four-week period. Unlike in Kasari et al. (2014), vocabulary was added periodically to participants' AAC systems over the course of intervention procedures in Romski et al. (2010). However, both the content and timing of adding vocabulary was a process initiated by the researcher outside of the study sessions, when a participating child was perceived to use a majority of the currently available aided AAC vocabulary (Romski et al., 2010). Participants started with an average of 15 available concept in their AAC systems and were provided only about eight additional concepts by the end of 24 weeks, or 24 hours of intervention (Romski et al., 2010). Participants in the current study added 11-48 new aided AAC concepts to their systems over the course of three hours of intervention. This stark difference in the rate of expressive vocabulary growth between participants in Romski et al. (2010) and the current study likely resulted from both the inclusion of just-in-time programming of vocabulary as well as the design of the aided AAC systems available to participants (i.e., VSD systems vs. traditional grid-based systems with picture symbols – see "Potential contributions of specific intervention components" for additional discussion).

All of the prior NDBI intervention research that included children on the autism spectrum and incorporated aided AAC (including the study by Kasari et al., 2014) used a small set of pre-programmed vocabulary concepts in a traditional grid format (see Pope et al., 2023 for a review) whereas the current study used VSDs with vocabulary concepts embedded as hotspots. The prior studies also did not include mechanisms to add additional vocabulary over the course of intervention. Thus, participating children had little to no opportunity to access and use new expressive vocabulary via aided AAC (only through gestures and speech approximations) – in contrast to the current study. Without access to AAC systems that are quick to learn, easy to use, supportive of language growth, and reflective of child interests, children on the autism spectrum with minimal speech often remain dependent on others to meet their daily needs throughout their lives, leaving them unable to attain their full potential, exercise choice, and make a positive contribution to society (McNaughton & Bryen, 2007).

VSD AAC research with just-in-time programming

Only two published studies have explored just-in-time programming of VSD AAC systems (Drager et al., 2019; Holyfield, Caron, Drager, & Light, 2019). All participants in both studies demonstrated notable gains in their number of communicative turns per session with the introduction of VSD AAC, just-in-time programming, and aided AAC input during intervention (Drager et al., 2019; Holyfield, Caron, Drager, & Light, 2019). In fact, all participants in Holyfield, Caron, Drager, & Light (2019), and most participants in Drager et al. (2019) showed relatively more robust gains in their frequency of communicative turns than participants in the current study (Holyfield, Caron, Drager, & Light, 2019 – increase of 13-26 turns per session; Drager et al., 2019 – baseline mean = 4; intervention mean = 30), and with slightly reduced intervention intensity and duration (1-2 15-minute sessions per week for 5-6 sessions = 75-90 minutes total).

However, participants in both Holyfield, Caron, Drager, & Light (2019) and Drager et al. (2019) were adolescent-age beginning communicators, with only a small subset on the autism spectrum. Though beginning communicators, these adolescent participants were chronologically older and thus likely had significantly more experience with social communicative interactions and turn taking, as well as exposure to language and communication more generally. This greater life experience may account for the relatively more rapid change observed in frequency of communicative turns than for the participants within the current study.

The accessibility and agency that VSD AAC systems with just-in-time programming offer to individuals with minimal speech likely accounts for the strong results demonstrated in both Holyfield, Caron, Drager, & Light (2019) and Drager et al. (2019) – as well as the current study. Notably, the results of these two studies with older participants demonstrate that naturalistic VSD AAC interventions targeting language, communication, and social participation need not be exclusive to young children. The reduced visual, cognitive, and linguistic, demands of VSD AAC (Light et al., 2019) can be equally effective at supporting the language and communication of older beginning communicators, in addition to creating a shared context for social interaction (Babb et al., 2021).

Potential contributions of specific intervention components

Numerous factors may have contributed to the increase in both participants' frequency of communicative turns and vocabulary growth during the intervention phase of the study. Intervention procedures included multiple active ingredients: aided AAC in the form of VSDs with digitized speech output, just-in-time programming of new aided AAC vocabulary in response to participant interests, and aided AAC input. Additionally, the same NDBI strategies included in baseline sessions were maintained during intervention and may have also contributed to participant gains in symbolic communicative turn taking, when combined with the specific added intervention components. Given the package nature of the intervention, it is not possible to definitively conclude what individual aspects or combination of components impacted participants' progress on communicative turns and unique vocabulary expression most significantly. However, several features of the intervention are likely to have contributed to this positive change. Importantly, the NDBI procedures may have interacted with other intervention components to support the frequency of participants' symbolic communication and/or vocabulary growth during intervention. However, the low, inconsistent, or decreasing rates of symbolic turns for five out of six participants and plateau in language growth for all participants during baseline sessions with NDBI strategies suggests that NDBI procedures themselves were not the most significant contributor to participant language and communication gains in intervention. The following sections consider the possible contributions of each of the intervention ingredients (i.e., the VSD AAC system with digitized speech output, just-in-time programming, and aided AAC input) to participant gains in symbolic communicative turns and unique expressive vocabulary use.

VSD AAC system

Aided AAC with speech output

The inclusion of high tech aided AAC with speech output generally may have been particularly supportive of increasing communication (vs. speech or gestures) in several ways. Activating a hotspot within a storybook page in the AAC app required less fine motor control than speech production, as well as most book-related signs/gestures. However, it is important to note that Owen still experienced some difficulty activating hotspots within the VSD system, signifying the importance of considering motor skills and appropriate access methods (including methods to improve direct access) during the AAC assessment process for all children who would benefit from AAC. Simply shifting the AAC system orientation from a more vertical position to slightly inclined horizontal position (about a 20-degree angle) allowed Owen to choose preferred books to read and select hotspots with greater success. The reduced motor demands of accessing expressive language via aided AAC may have contributed to the observed increase in participants' symbolic communicative turns as well as unique vocabulary concepts expressed, as participants could access a wide range of expressive vocabulary independently.

The high-tech VSD AAC system used in this study included speech output when a vocabulary concept was selected. Thus, participants encountered a higher frequency of consistent spoken models of a particular vocabulary concept, while also attending to the symbolic representation of that concept within the AAC system – as compared to receiving only speech input from the researcher alone. The consistency and frequency of this speech output from the aided AAC system may have potentially supported both an increase in communicative turns and expressive use of a greater number of concepts (Kasari et al., 2014). In addition, participating children in the current study were able to exert some control over the timing and frequency of the speech output (via aided AAC), as they could select hotspots independently at any point during storybook reading sessions in intervention. Individuals on the autism spectrum may experience greater challenges integrating temporally synchronous sensory input (e.g., auditory input from speech and visual input of the associated concept; Stevenson et al., 2016). Participants having greater agency over the timing of speech output from the aided AAC system when selecting hotspots independently could have mitigated some of these potential challenges with integrating sensory input from the visual and auditory systems.

In contrast to most traditional grid-based AAC technology, which uses synthesized speech output, VSD AAC systems generally use digitized speech output (i.e., recorded natural speech, as was the case in the current study). By enabling communication partners to record speech to play upon activation of a hotspot, VSD AAC output naturally includes the affective qualities of human speech associated with prosody, intonation, and pitch. Research indicates that affective speech is more effective at attracting the attention of young children than neutral speech, including young children on the autism spectrum (Pierce et al., 2023). Thus, the digitized speech output from the VSD AAC system used in this study – that included these natural prosodic features – may have been more engaging for participating children than the synthesized (i.e., computer generated) speech typical of traditional grid-based AAC systems. In fact, in the current study, VSD hotspot output that had more exaggerated prosody, pitch, or intonation (mostly social interaction words) represented some of participants' most frequently expressed concepts (e.g., "Oh no!" or "Whee!"), further suggesting the power of these natural affective speech features in supporting socially communicative interactions for young children on the autism spectrum.

The participants' hotspot selections not only resulted in speech output from the aided AAC system. According to the intervention procedures, these participant turns also resulted in contingent responses from the researcher that included spoken language and aided AAC input with associated hotspot speech output. The researcher's contingent responses (via speech and aided AAC with associated speech output) increased the participant's overall exposure to that language concept. Having greater agency over exposure to the speech output for language concepts – as well as the ability to influence the researcher's reciprocal language and communication behavior – may have increased participants' motivation to communicate expressively, leading to a positive increase in symbolic turn taking and use of vocabulary concepts expressively.

Language input via speech or signs/gestures is only available to a child for a short duration of time (i.e., when the communication partner is speaking or signing that concept) and is contingent upon attention to the communication partner. Children have limited agency over the speech or signs actually produced by their communication partners. Research suggests that when children on the autism spectrum use less expressive speech themselves, the complexity of language input from their caregivers may be reduced (Smith et al., 2022). Children on the autism spectrum who have lower rates of reciprocal joint engagement with their communication partners also tend to have less robust expressive language growth (Bottema-Beutel et al., 2014). Thus, the aided AAC system used in this study provided participating children a means of expressive communication and language input that did not require continuously shifting attention between a communication partner and the activity, was not contingent upon high levels of reciprocal joint engagement, and also allowed participants greater control over their exposure to language concepts. These factors reduced both the attentional and social demands of communication and language learning, potentially leading to more frequent symbolic communication. In turn, more frequent expressive communication by the participants increased the social responsiveness of the researcher (i.e., contingent responding), potentially creating greater opportunities for joint engagement while also leading to increased language exposure.

The gains in expressive communication via aided AAC observed in the current study came with no negative impact on speech production. However, participants did not increase their speech production as a result of the intervention, though research suggests that increases in speech are often associated with AAC intervention (Millar et al., 2006). In fact, increased speech production in the current study may have been expected to be more likely, given the participants' independent access to speech models via voice output from the VSD AAC system. However, total intervention time was minimal – approximately three hours over 12 sessions. Research suggests that the lag time between the introduction of aided AAC and even a modest increase in speech production may often take substantially more time (greater than 25 intervention sessions; Millar et al., 2006). Additionally, some researchers suggest that the cognitive, linguistic, and operational demands of learning to use an aided AAC system may initially be too great to also transfer immediately to speech (Romski & Sevcik, 1996). However, once aided AAC users gain greater automaticity in those processes, subsequent increasing in speech production may ensue (Romski & Sevcik, 1996). It is unclear what impact continued intervention may have had on increasing participants' speech production.

VSD AAC technology with digitized speech output

The VSD AAC system used in the study presented unique supports for symbolic communicative turn taking and expressive vocabulary growth. Hotspots within a VSD system are contextualized within the relevant scene, available at all times without a model, and require less fine motor control to activate than most signs/gestures and all speech. In fact, all participants but one (Owen) were immediately able to navigate through the AAC system, selecting preferred books, navigating to preferred storybook pages, and even zooming in on parts of a storybook page. All of these characteristics reduced the language, attention, motor, and cognitive demands of using a VSD AAC system to communicate. Moreover, hotspot selection by a participant resulted in intelligible spoken output, unlike initial speech approximations or sign approximations. Participants' expressive communication via aided AAC was thus more likely to be recognized and interpreted correctly by the researcher, leading to a higher likelihood of relevant related language input for the child via the researcher's contingent response.

Modeled gestures and speech, on the other hand, are decontextualized in space and require participants to shift attention from the storybook to observe, are only modeled ephemerally for the few seconds when a partner is communicating them, and typically require increased fine motor control for participants to enact. In addition, greater generalization skills and well-timed shifting attention are required for a participant to make the same connection between touching part of a storybook illustration and the gesture or spoken word a communication partner may model in reference to that concept.

VSD layouts require even fewer demands on joint attention than traditional grid-based AAC systems, as participants do not need to shift their attention from the physical storybook to the AAC system – either to communicate expressively or to observe the researcher's aided AAC input. Shifting attention, especially within socially interactive contexts, is often challenging for young children on the autism spectrum (Mo et al., 2019). Thus, the VSD layout specifically may have increased symbolic communicative turns by reducing demands of shifting attention, potentially resulting in increased engagement, as well. Additionally, the embedded nature of vocabulary concepts in the VSD system may have supported growth in unique concept expression, by increasing the likelihood participants would observe a language model from the researcher.

Embedding vocabulary within the storybook scene also naturally provided contextual support to aid in comprehension of the associated vocabulary concept. VSDs represent language within the context in which it is learned and used, as well as maintaining the visual and proportional relationships between items within a scene (Holyfield, Caron, & Light, 2019; Light et al., 2019). Participants did not need to learn to pair both a new symbol representation and a spoken label to a particular language concept, as vocabulary was represented within the book illustrations themselves. Traditional grid-based systems generally include more abstract picture symbols to represent vocabulary, requiring children to map on yet another representation to that language concept (i.e., the picture symbol). Additionally, even if vocabulary concepts were represented within a traditional grid-based AAC system using pictures from within the storybook illustrations (as in the comprehension probe task), the contextual support of the entire storybook scene would be missing. In fact, grid-based AAC systems can be challenging for neurotypical children to use successfully for generative communication (Trudeau et al., 2014). By contrast, all participants in the current study began to produce 2-word combinations using the hotspots within the VSD system.

Evidence suggests that VSDs also offer visual cognitive processing advantages for both young children generally, as well as individuals on the autism spectrum specifically (Light et al., 2019). The contextualized nature of the visual scene allows for rapid visual cognitive processing, supporting quick identification of – and attention to – the key features of the scene (e.g., people, shared activities; Wilkinson & Light, 2014). In contrast, traditional grid display AAC systems decontextualize language representations from the natural scene, removing supports to visual cognitive processing and introducing multiple distractors (Light et al., 2019). Taken together, these visual, cognitive, linguistic, and motor supports associated with VSDs may have allowed participants to allocate greater resources to social communicative turn taking and semantic development.

Just-in-time programming in response to participant interests

Access to new, participant-driven vocabulary via just-in-time programming was also a probable contributing factor to the observed increase in both the frequency of symbolic communicative turns and language growth. Vocabulary was only programmed just-in-time in response to participant interest, and thus would have been likely to include a high percentage of concepts that participants were motivated to communicate – potentially increasing their communicative turns. Additionally, participants' vocabulary was dynamic. They could communicate preferred concepts for which they already had a hotspot, reprogram the same preferred concept on multiple storybook pages, and gain access to new, engaging expressive vocabulary concepts the moment they encountered them during social interactions. With just-in-time programming, participants could easily indicate interest in relevant parts of the illustrated scene on the storybook page, resulting in programming of new and motivating expressive vocabulary; thus, the children gained greater agency over their own expressive communication. A large, dynamic vocabulary set – constructed with continued input from the participant – would be very likely to support steady expressive vocabulary growth, as demonstrated by the current study results.

Critically, every participant indicated an interest in adding vocabulary programmed just-in-time, and all participants then used at least a third of this vocabulary expressively – with most participants communicating over 50% of these concepts. Interestingly, the fact that participants did *not* activate every hotspot within each book indiscriminately (including their own just-in-time programmed hotspots), and instead increased their unique vocabulary use gradually over time, suggests that participants were, in fact, opting to communicate specific concepts that were motivating to them, as opposed to pressing on buttons on the screen simply because they were available, or only in imitation of the researcher.

For most participants, approximately half of the total unique concepts they communicated via VSD AAC over the course of the study were only available as a result of just-in-time programming, indicating the power of this intervention component on unique vocabulary growth. Without access to an AAC system that was responsive to child interests and allowed for quick and easy programming, participants would have lost access to almost half of their book-related aided AAC expressive vocabulary (including some of their most highly preferred concepts), as well as most of their agency over both their language input and language output. These results clearly demonstrate the striking importance of access to both pre-programmed AAC (within a developmentally appropriate AAC system), as well as vocabulary programmed just-in-time in response to participants' interests. Most traditional high tech aided AAC systems do not support this sort of quick, spontaneous, and child-directed vocabulary programming, and thus may in fact be constraining the communication and language development of the young children who use them, to some extent.

Importantly, vocabulary added just-in-time was essential to support participants' aided AAC semantic relation combinations. Only one hotspot was preprogrammed on each storybook page, limiting the possible communicative options on a particular page to a single concept. By indicating an interest in adding new vocabulary, the participants themselves were instrumental in adapting their own AAC systems to support the next stage in language development. Participants' use of generative 2-word utterances also suggests that VSD AAC systems may be one appropriate communication support not only for children in the earliest stages of initial semantic development, but also those children who are starting to transition into the early semantic relations stage of language learning. However, a VSD AAC system in isolation may not be sufficient to continue to support this language transition into multi-word utterances. For these children, additional AAC supports are necessary that better support morphosyntactic development (such as those based upon traditional orthography).

Aided AAC input

Aided AAC input was also a likely contributor to the increased number of symbolic communicative turns taken by participants, as well as the unique vocabulary concepts expressed. Strong evidence supports the effectiveness of aided AAC input in supporting the language and communication development of individuals with limited speech (O'Neill et al., 2018). By augmenting spoken language input to the participant via aided AAC input, the researcher provided direct models of aided AAC communication within an interactive, naturalistic context – via an expressive modality that may have been more accessible to most participants than speech or signs/gestures (see discussion above). The researcher's aided AAC input thus provided incidental teaching of how to use the hotspots within the VSD to communicate, within the naturalistic context of the storybook reading activity. Even if participants initially only imitated the researcher's hotspot selections (without the intentional goal of communicating that particular concept), those hotspot activations still resulted in a contingent response from the researcher, supporting reciprocal social interaction and increasing the participant's exposure to both the target and related language concepts. Thus, aided AAC input encouraged the same sort of social communication and language learning opportunities for participating children on the autism spectrum with minimal speech that are available to children who use speech, who often imitate the spoken words of their communication partners (Nelson, 1973).

Aided AAC input was also likely a notable contributor to participant gains in expressive vocabulary use. Simply because aided AAC vocabulary was available did not guarantee that participants would begin to use this vocabulary expressively. Modeling and expansion of language by communication partners is critical to build vocabulary. Young children who use speech are exposed to new language concepts through their communication partners' speech utterances and are then able to try out these new words themselves via that same modality (speech), receiving feedback and expanded spoken language input from partners. However, when young children who use AAC are only provided with speech input, there is an asymmetry between the mode of their language input (speech) and language output (aided AAC; Smith & Grove, 2003). This creates barriers to expressive vocabulary growth. Thus, the aided AAC input provided by the researcher gave participants additional semantic input via a symmetrical modality of participant expressive output (i.e., aided AAC), as well as repeated models of how to use the VSD AAC system functionally during communicative interactions. However, the vocabulary available in the AAC VSD system was limited; thus, the aided AAC input provided by the researcher in this study represented telegraphic expressive communication, including only one or two of the words within the researcher's longer corresponding spoken utterances.

Additionally, the current study procedures included not only aided AAC input, but also prompting to encourage participants' own expressive use of the aided AAC system. Prior research suggests that actively prompting young children with language delays to use an aided AAC system expressively may actually have a greater impact on both communication rate and vocabulary size than simply providing aided AAC input (Romski et al., 2010). The current study included less direct prompts for expressive aided AAC use than the prior research (i.e., expectant delays and gestural prompts in the current study vs. verbal and physical prompts in Romski et al., 2010). However, the current study procedures did include a combination of both aided AAC input as well as prompting for aided AAC output by participants – potentially a more powerful combination to support communicative turns and vocabulary growth than aided AAC input alone.

Word combinations

All participants produced at least one two-word combination via aided AAC over the course of the intervention phase. The emerging use of these two-word semantic relations in participants' expressive communication suggests the power of modeling via aided AAC input. Participants were not actively taught to combine concepts together during intervention; their only exposure to these types of word combinations was through the researcher's aided AAC input when expanding upon participant communication. Additionally, participant word combinations were only observed via aided AAC – not in participants' speech or gestures.

Research specifically focused on supporting word combinations for children who use AAC has shown promising results (Binger et al., 2008; Binger et al., 2010; Binger et al., 2017). Caregiver-mediated interventions during shared storybook reading directly targeting modeling of two-symbol aided AAC utterances on traditional grid-based aided AAC systems resulted in significant increases in the number of multi-symbol messages produced by children who use AAC – both for children with age-typical receptive language skills (Binger et al., 2008; Binger et al., 2010) as well as those with significant language delays (Binger et al., 2010). Additionally, intervention targeting young children with severe speech disorders and typical receptive language skills has also been successful in teaching specific semantic-syntactic forms using dynamic assessment procedures within a traditional grid based aided AAC system (Binger et al., 2017).

Notably, participants in the current study received significantly less exposure to aided AAC word combinations than in the intervention studies by Binger and colleagues that were specifically designed to support the production of two-symbol aided AAC messages (Binger et al., 2008; Binger et al., 2010; Binger et al., 2017). In the current study, the researcher only modeled two-word aided AAC combinations during intervention when providing an expansion as part of a contingent response to participant communication *and* when two relevant VSD hotspots were available on that storybook page. Thus, participants were only exposed to models of two-word aided AAC input when: 1) they made a communication attempt that resulted in a contingent response from the researcher; 2) at least one additional hotspot had been added just-in-time to the storybook page (as only one hotspot was preprogrammed per page); and 3) there were two available hotspots on the current page that were relevant to the researcher's spoken language expansion. In contrast, participants in Binger et al. (2008) and Binger et al. (2010) experienced multiple (3+) two-symbol aided AAC models on every storybook page, and participants in Binger et al. (2017) were exposed to concentrated modeling of the target semantic-syntactic forms. Additionally, most participants (all but two) across these three studies had age-typical receptive language skills, and none were on the autism spectrum, unlike the participants in the current study. Thus, the results of the current study build upon the previous research by suggesting that even with less frequent exposure to two-word aided AAC models, young children on the autism spectrum with significant language delays can also start to demonstrate initial use of two-word aided AAC combinations.

However, cumulative evidence suggests that young children (including typically developing children ages 3+ who were asked to use AAC for research purposes) – like the children in this study – tend to produce mostly single-word utterances when they use picture-based aided AAC without direct encouragement to produce longer messages (Binger & Light, 2008). In typical speech development, children tend to start combining words once they are using about 50 different words expressively, and understand around 200 words (Bochner, 2008). Thus, the high frequency of single-word use by children without disabilities who were three years of age or older reported in the research (Binger & Light, 2008) is clearly not representative of their receptive or expressive language knowledge, but may instead reflect the impact of the aided AAC systems themselves (all grid-based and using graphic symbol representations).

When aggregated across modalities (speech, sign, aided AAC), most participants in the current study were reported to use close to 50 (or more) individual words, and/or understand over 130 words prior to study participation. Thus, at least some participants may have actually been approaching (or have already surpassed) the receptive and/or expressive benchmarks in neurotypical language development associated with the emergences of initial word combinations. Thus, these children began to produce two-word aided AAC messages when given access to an AAC system that imposed minimal learning demands, after only limited exposure to modeled two-word aided AAC combinations.

Participants were included in the current study if they fell clearly into the First Words stage of language development based upon the Tager-Flusberg et al. (2009) criteria – and in fact many of them only just met the benchmarks for the First Words stage. However, it is important to note that the criteria proposed by Tager-Flusberg et al. (2009) *only* consider speech. Many children on the autism spectrum who have minimal speech (like the children in the current study) use multiple means to communicate; focusing on speech production alone may serve to underestimate their language skills. When considering both caregiver report and performance in the current study, it is evident that the participants had a range of language and communication skills. More comprehensive language development benchmarks are required for young children on the autism spectrum that extend beyond speech production and also consider multimodal communication in the assessment procedures.

Comprehension of spoken language

Participants in the current study generally demonstrated low accuracy matching book-related vocabulary targeted within the main comprehension measure to the spoken word, across all three study timepoints. However, these targeted concepts were pre-determined by the researcher given specific criteria (e.g., appeared more than one time in a specific book, were imageable within the scene, nouns and verbs only, no character names). Post-hoc analyses indicated that the preset target concepts had minimal overlap with the highest frequency expressive vocabulary for most participants. The concepts that did overlap were predominantly verbs, which were the targets of modeled (and often imitated by participants) signs/gestures. The researcher did not perform the associated sign/gesture for verbs during the comprehension task, and thus participants were missing what might have been a crucial bridge for demonstrating their understanding of the speech label for these concepts.

In addition, all participants tended to gravitate toward the same subset of 2-3 of their five storybooks, choosing to read the other 2-3 available books rarely (or never). Participants also had unequal exposure to specific pages within each book, as they often reread preferred pages multiple times, but skipped over other pages. The lack of significant progress identifying book-related concepts in relation to the spoken word (as measured by this preset comprehension task) may have been due in large part to the fact that the vocabulary concepts tested were not representative of the concepts that the participants encountered most frequently (or at all) during the shared storybook reading.

Most participants had better accuracy (above chance levels) on the individualized post-hoc spoken language comprehension task than on the main comprehension measure. This suggests that most participants did, in fact, either develop or already have an understanding of the spoken words for a subset of the concepts that they were communicating via both aided and unaided AAC. However, none of the participants demonstrated 100% accuracy identifying their most frequently expressed vocabulary concepts. This may be related to several factors. Although the task format for both of these measures was modeled on standardized receptive language assessments, this presentation of administration included some inherent challenges that could have negatively impacted participant accuracy. Book illustrations were used to represent the target vocabulary, but only a small portion of the relevant page, decontextualized from the surrounding book scene. Spoken language comprehension measures also had very different task expectations (touching the picture that matched a spoken word) than typical storybook reading sessions (touch a picture about which you want to communicate). In the storybook reading sessions, there were also no “right” or “wrong” answers – all participant communication attempts resulted in a contingent response from the researcher. This differed from the comprehension probes, which were designed to measure participants' spoken word identification accuracy, and in which participants received only general reinforcement (e.g., "Great job working!"). These measures were only completed three times over the course of the study, so it may have also been a challenge for participants to adjust to the discrepant task expectations. Additionally, though targets for the individualized post-hoc comprehension measure represented each participant's most frequently communicated vocabulary, those concepts near the end of this list still had low total communication rates over the course of the study for some participants (e.g., only communicated a total of 2-3 times).

Despite these inherent challenges within the comprehension measure tasks, an alternative (though not mutually exclusive) explanation may be that participants used vocabulary expressively for which they did not have a strong underlying understanding of the connection between the spoken word and image used to represent that concept within the task. This pattern could be reflective of a sequence of language learning in which expression via aided AAC may precede (and in fact help bolster) strong comprehension of the spoken word (Romski & Sevcik, 1996), and/or understanding of the underlying vocabulary concept but not the spoken word. In fact, neurotypical children in the early stages of language learning may similarly use expressive language as a method of supporting comprehension. Young children often imitate the spoken utterances of their communication partners (Nelson, 1973). This behavior elicits feedback from the communication partner about the imitated word, providing additional cues to word meaning, as well as exposure to other related vocabulary through language expansions. Participant performance on both spoken language comprehension measures in the current study suggests that at least some of the participating children's expressive communication (through not only aided AAC but also signs/gestures and speech) may have served a similar purpose to support their own language learning of those concepts and/or spoken labels.

However, it is important to note that the vocabulary concepts that participants communicated most frequently did not necessarily overlap perfectly with the language concepts for which participants received the most exposure. All but one participant (Owen) quickly started to navigate between books and book pages independently. In both baseline and intervention, participants appeared to use navigating away from and back to the same page repeatedly as a means of requesting that the researcher read that page multiple times (usually those that contained a book sign/gesture and related sound effect – e.g., "Whee!" "Oh, no!"). While these were often concepts that the participants themselves communicated expressively during baseline, intervention, or both, this was not always the case. For example, during most sessions in intervention, Lila would navigate several times between the two pages with the word "decorate," which included the researcher performing the sign for "decorate." Both of these storybook pages also had a hotspot available for "decorate" throughout all of intervention. Despite frequently visiting those pages, Lila only communicated "decorate" expressively one time during the study by activating the associated hotspot. However, during the post-intervention main comprehension probe, Lila performed the sign for decorate immediately after the researcher spoke the word, and then quickly indicated the correct photo representation. Lila did not accurately identify "decorate" in either the pre- or post-baseline comprehension probes, suggesting her learning of this concept and associated speech label over the course of intervention.

This example illustrates the importance of taking into account multiple factors when considering the process of word learning for young children. Learning new vocabulary includes both a conceptual understanding of the associated referent in the environment (i.e., the concept that the word represents), as well as pairing the spoken word to that referent. Repeated exposure to the spoken word is essential when learning new vocabulary (Nelson, 1973), with approximately 10 exposures generally being sufficient for pairing the spoken word to the referent in neurotypical language development (Gray, 2005). Children may also use a production strategy to facilitate word learning – i.e., using a newly-encountered word expressively to receive confirmative feedback on its meaning, along with additional related language input (Nelson, 1973).

Additionally, the sources of input associated with exposure to a language concept may also impact word learning. In the current study, both understanding of noun concepts and pairing of the spoken word to the concept may have been facilitated by participants' attention to that character or object within the storybook illustration, in conjunction with activation of the hotspot speech output or the researcher's spoken label for that concept. For verb concepts, the inclusion of related signs/gestures as an input modality may have supported both comprehension of the concept (e.g., what does it mean to "decorate"?), as well as pairing of the spoken word with that concept (e.g., observing the sign/gesture for "decorate" while hearing the spoken label, as opposed to only seeing the static illustration). These signs/gestures also provided opportunities for embodied learning of verb concepts (Engelstad et al., 2020), as participants themselves could also imitate the related action, experiencing the meaning of that verb concept themselves. Observations of typically developing children suggest that the degree of reliance on these different language learning strategies varies from child to child (Nelson, 1973). However, it is safe to assume that participants' expressive use of book-related vocabulary in the current study was not the only factor impacting their comprehension of book-related spoken words.

Caregiver social validity

Results from social validity questionnaires indicated that caregivers viewed intervention procedures that included VSD AAC, just-in-time programming, and aided AAC input as very supportive of their child's communication, participation, and enjoyment, and would recommend the activity to others. They also generally rated intervention procedures as more supportive of all of these factors than baseline sessions. All but one caregiver rated the baseline procedures with NDBI strategies as less supportive across all of these domains, with several caregivers disagreeing or strongly disagreeing that the baseline activity was supportive of their child's communication, participation, and enjoyment. Given the growing prevalence of traditional NDBIs (that do not include aided AAC) within early intervention, this feedback is critical, and suggests that caregivers may not perceive these interventions as particularly beneficial to their children on the autism spectrum with minimal speech. Caregivers of children who communicated symbolically with the lowest frequency during baseline had the least positive views of the baseline NDBI procedures, further underscoring the critical importance of including aided AAC systems into these intervention for children with the greatest needs.

Importantly, all caregivers strongly agreed that both baseline and intervention procedures seemed feasible for a parent or teacher to complete with the child, suggesting that the addition of the VSD AAC component (along with just-in-time programming and aided AAC input) into NDBI strategies during intervention did not make the intervention appear more challenging for a caregiver or teacher to implement. This aligns with the results of previous research suggesting that programming VSDs during communicative interactions is accessible and efficient for communication partners (Caron et al., 2016; Holyfield, Caron, & Light, 2019). Given the importance of AAC intervention that occurs throughout the day and across multiple contexts, positive caregiver perceptions about the feasibility of implementing the study procedures themselves is highly encouraging.

Clinical implications

The results of this research demonstrate that NDBI procedures paired with an aided AAC system designed to support beginning communicators is a powerful combination. VSD AAC with digitized speech output, just-in-time programming, and aided AAC input within the context of NDBI strategies increased both the frequency of symbolic communication and the expressive vocabulary growth of young children on the autism spectrum with minimal speech in the First Words stage of language development. Importantly, these language and communication gains expanded beyond the realm of object requesting, suggesting that similar intervention strategies across contexts would likely be effective for many young children on the autism spectrum with minimal speech. However, it is important to stress that AAC must be a good fit for the skills and needs of the individual. The results of this study suggest VSD AAC systems may be a valuable tool to promote communication, language learning, and social interaction for young beginning communicators, and potentially those children who are starting to transition to early semantic relations.

Developmentally appropriate aided AAC should be incorporated into language interventions for young children on the autism spectrum with minimal speech from the outset (in line with results from Kasari et al., 2014). Taking a wait-and-see approach to AAC intervention leaves children without access to effective communication during critical early language learning developmental years. In the current study, even participants who used a small number of spoken words and signs/gestures in baseline quickly reached a plateau in their expressive vocabulary growth, and generally demonstrated a more variable number of symbolic communicative turns per session during baseline than intervention. Critically, results from Kasari et al. (2014) suggest that these potential gains from the early introduction of aided AAC cannot be easily recovered when AAC is later introduced.

Systems that are easy for both caregivers and children to program and use – and can be integrated into existing activities and routines (such as the VSD AAC app in this study) – may lower the potential barriers many communication partners feel in supporting their children's use of traditional aided AAC systems (Laubscher et al., 2022). In fact, all caregivers strongly agreed that intervention procedures that included the VSD system would be easy for a caregiver or teacher to implement, at least in the context of shared storybook reading. Access to these types of AAC systems in early development would likely have a substantial benefit on the long-term language and communication trajectories of young children on the autism spectrum with minimal speech.

Once available, all participants showed a preference for using the VSD AAC system as a primary mode of communication. However, no participants completely abandoned speech or signs/gestures as a communication mode during intervention. Additionally, every participant was able to imitate and use expressively at least one book-related sign/gesture during baseline. It is critical that children who use AAC maintain access to this type of multimodal communication, and are provide language input, support, and validation for all communication modes. No individual uses only one mode of communication. The language and communication growth of young children on the autism spectrum with minimal speech similarly benefits from a multimodal perspective.

When given the opportunity, participating young children on the autism spectrum were able to participate actively during communicative interactions to exert greater influence over their expressive communication and receptive language input. Just as neurotypical children who use speech have agency over what they communicate and how they influence their caregivers to provide specific language input, the participants in this study appeared eager to gain some control over their communication, as well as the input they received from the researcher.

Additionally, the results of this study further underscore the fact that adult communication partners are not always the best predictors of the vocabulary a young child will want to communicate. There was little overlap between the vocabulary targeted in the predetermined comprehension of spoken language measure and participants' most frequently communicated concepts. Participants also consistently indicated an interest in having new vocabulary programmed into the VSD AAC system. Importantly, though there were many similarities, the specific vocabulary children programmed and used was not identical across children. These results suggest it is essential that the individual children themselves are included in selecting – and frequently updating – their own AAC vocabulary. As demonstrated in this study, accessible and developmentally appropriate AAC systems allow children to be included in this process with relative ease. In fact, neurotypical children as young as 10 months have successfully engaged in at least some steps of the process of programming a VSD (Holyfield et al., 2017). Furthermore, the evidence suggests that programming VSDs during communicative interactions is accessible and efficient for communication partners (Caron et al., 2016; Holyfield, Caron, & Light, 2019). Lila's quick uptake of the steps of programming a hotspot indicates that this process can also be accessible and efficient for young children on the autism spectrum.

Participating children also communicated (and indicated interest in programming just-in-time) a variety of different types of language concepts, but predominantly nouns, concrete verbs, and socially motivating interjections/other sound effects. Importantly, children were active participants in the vocabulary selection process, indicating their interest in various language concepts that were then programmed into the VSD AAC system. Participants in this study also demonstrated expressive use of a variety of concepts, increasing their unique expressive vocabulary relatively rapidly over the course of a short period of intervention, and setting the stage for the emergence of early semantic relations.

These results have important implications for language learning in children on the autism spectrum with minimal speech who use AAC. All participants in this study were able to rapidly use new expressive vocabulary programmed as hotspots in VSDs in a relatively short period of time. Concepts consisted overwhelmingly of concrete nouns and verbs (see Appendix K), as well as interjections (mostly sound effects that served to promote social engagement – e.g., “whee!”). These patterns align with early neurotypical language and communication development, which includes the child as an active participant in their own language learning, is dominated by nouns, some verbs, and social concepts (Crais et al., 2004; Fenson et al., 2007; McDonough et al., 2011), and proceeds through early semantic development at a relatively rapid pace (Gilkerson et al., 2018).

By contrast, many clinicians who provide AAC intervention for young children on the spectrum may focus on a core vocabulary approach (Thistle & Wilkinson, 2015). Core vocabulary is typically considered a small set of concepts that occur with the greatest frequency within the lexicons of typically developing toddlers (Laubscher & Light, 2020). These concepts are generally less concrete (e.g., “that,” “it,” “can;” Laubscher & Light, 2020), and thus can theoretically be used in multiple situations across contexts.

One potential goal of a core vocabulary approach is to limit the number of vocabulary concepts a child must learn in order to communicate functionally across contexts. However, participant rates of unique vocabulary growth in this study demonstrate that children on the autism spectrum with minimal speech in the First Words stage of language development can quickly add vocabulary to their expressive repertoires. Additionally, when given greater agency over the vocabulary available to them (through just-in-time programming), the type of concepts communicated by participants in this study reflect patterns of early vocabulary learning in neurotypical development, with a focus on concrete nouns, verbs, and concepts that support reciprocal social interaction (Crais et al., 2004; Fenson et al., 2007; McDonough et al., 2011). Taken together, these results suggest that young children on the autism spectrum with minimal speech who are in the early language learning stages (e.g., First Words, early semantic relations) may benefit from AAC systems that include concrete nouns and verbs, engaging social words and sound effects, inclusion of personalized vocabulary that reflect the interests of children themselves, and are updated frequently with new vocabulary that meet these benchmarks.

Given the nature of the shared storybook reading activity, participants communicated over the course of the study almost exclusively for the purposes of social engagement, to comment, or to maintain reciprocal interactions. Challenges with social communication are a core diagnostic characteristic of autism (American Psychiatric Association, 2013). Thus, the shared storybook reading context of study procedures specifically promoted participant language and communication within an activity that was designed to support these core social communication challenges for young children on the autism spectrum.

The focus on using expressive vocabulary for social engagement and reciprocal interaction was a departure from participants' typical communicative functions in day-to-day life (as reported by caregivers), which mostly revolved around requesting objects. However, all participants experienced success using their symbolic expressive communication for these less familiar communicative functions. This contradicts some perceptions that beginning communicators on the autism spectrum will only find initial success with aided (or even unaided) AAC within the context of object requesting. However, the promising results of this study do align with the developmental sequence of early neurotypical communication development, in which social interaction behaviors emerge as one of the earliest communication domains (Crais et al., 2004).

In line with previous related research (Kasari et al., 2014), the results of this study clearly demonstrate that young children on the autism spectrum with minimal speech are both motivated and capable of communicating much more than the object requests that often dominate both research and clinical practice. Social communication is a central challenge of autism (American Psychiatric Association, 2013). It is critical that these children are also provided the opportunity to develop their social communication skills, embedded within the context of motivating, engaging activities and with appropriate communication supports.

Research implications

This study expands upon past work by incorporating measures to capture participant learning of spoken language comprehension across the course of the study. Criterion referenced measures targeting language comprehension are almost nonexistent in the NDBI literature (Pope et al., 2023). Neglecting the receptive domain of language development limits the conclusions that can be drawn about changes in expressive communication, underlying factors contributing to aided AAC use, and potential mechanisms for language learning for children who use AAC.

Work by Sevcik (2006) and colleagues suggests that underlying language comprehension can have a significant impact on the way children learn and use aided AAC systems, with direct implications for AAC intervention and system design. Children who have already developed more robust underlying receptive language knowledge may experience fewer cognitive and linguistic demands learning and using AAC systems, as they are mapping preexisting language knowledge onto a new system of organization and representation (Sevcik, 2006). By contrast, children in the earliest stages of language development are often learning formative language and communication skills simultaneously with the functional use of an aided AAC system (Sevcik, 2006). For these children, access to AAC systems that minimize the cognitive, linguistic, visual, and motor demands of learning and using an aided AAC system is especially critical – and may even support the process of language acquisition.

Participating children's true underlying receptive language knowledge in the current study is unknown. However, participants varied in the immediacy and level of their response to the intervention procedures, in both the number of communicative turns they took and their rate of growth in unique vocabulary concepts expressed. While there were likely numerous contributing factors, it is possible that participants with more developed underlying receptive language knowledge may have demonstrated larger initial gains and/or a more rapid rate of increase in their pragmatic (i.e., number of communicative turns) and/or semantic (i.e., unique vocabulary concepts expressed) growth. Importantly, all participants demonstrated notable changes in both domains. Additional future research is needed investigating both the factors that impact learning and use of aided AAC system for beginning communicators (including receptive language knowledge), as well as the process of early language learning for young children who use AAC.

The current research also demonstrates the strengths of integrating current research knowledge and intervention strategies across different disciplines that aim to promote language and communication growth for children on the autism spectrum. The study procedures blended developmental psychology perspectives on intervention (where most NDBIs originate) with current knowledge on developmentally appropriate AAC technology, resulting in significant gains in the language and communication of participating children. Clinicians and researchers are encouraged to consider the potential benefits of this type of interdisciplinary approach to early intervention – a collaborative viewpoint from which NDBIs initially originated.

Limitations and future research directions

This study represents a first step in exploring a novel approach to early intervention targeting language and communication for young children on the autism spectrum with limited speech. However, as a first step, there are several limitations to consider, as well as important future directions.

Typical of single case research, this study included a small number of participants, limiting the external validity and generalizability of the results. However, the strength of the study findings are enhanced by the replication of the data (Horner et al., 2005). Additionally, participants were relatively homogeneous across age, race, ethnicity, and degree of characteristics associated with autism. Although the participant cohort included two girls, there was still a much greater representation of boys on the spectrum – a pattern that unfortunately continues to be representative of both intervention research and diagnosis rates (Loomes et al., 2017; Watkins et al., 2014). Replication of these results with a larger, more diverse group of participants is essential.

Critically, children from underrepresented racial and ethnic groups may be less likely to access AAC systems and services in the first place. Though limited, research suggests that Black preschool-age children with developmental disabilities (including autism) may receive significantly fewer AAC intervention hours per week, even with access to these services (Pope et al., 2022). Future research that specifically includes populations at risk for reduced access to AAC intervention services is crucial.

Both research assistants coding the study data were blind to the overall goals of the study. However, the presence of hotspots during intervention served as a cue to study phase. Additionally, the main research assistant completed study coding for videos on a weekly basis as they were recorded. Although the order of videos within each weekly batch was randomized, the sequential nature of coding videos each week also served as a cue to session order. However, across both intervention legs, participants were all in different study phases at the same point in time, naturally interspersing data coding within baseline, intervention, and maintenance across participants. Additionally, these limitations were addressed in part by calculating interobserver agreement for a subset of videos coded for each measure by the second research assistant. This coding was completed with all targeted videos randomized in order, removing the potential impact of sequence effects.

Maintenance data were only collected for one leg of the study. However, maintenance data for number of communicative turns remained at or above intervention levels for those three participants. This offers good evidence that the symbolic communication rates attained by participants would be maintained across time. Additionally, maintenance for that first leg was collected at 2-3 timepoints, covering a total time from the end of intervention of up to 8 weeks. However, additional maintenance data from the second leg of participants would have strengthened these conclusions.

Lila demonstrated relatively high initial expressive use of modeled signs/gestures – though still significantly less than would be expected from a neurotypical child her age who relies on speech (16 vs.

73 unique concepts communicated in one 10-minute naturalistic sample; Vallotton & Ayoub, 2010). It is possible that she may have continued to increase her rate of symbolic turn taking during baseline with access to a growing set of modeled signs/gestures, as opposed to the finite predetermined set modeled during each storybook. However, in total, 23 unique book-related signs/gestures were available to Lila within her set of five storybooks (five signs/gestures per book, with two overlapping across books). Over the course of baseline, Lila communicated 13 of these book-related signs/gestures at least once – only slightly more than half – and at an overall decreasing rate. This may have been related to a lack of interest in communicating some modeled signs/gestures, and/or less interest in reading some of her set of five storybooks (and thus less exposure to the associated signs/gestures). Thus, introduction of new signs/gestures in response to Lila's interests (i.e., "just-in-time" language modeling via sign/gesture) may have been an effective strategy to support increasing symbolic gestural communication (and vocabulary growth) during baseline, without the introduction of aided AAC. Modeled gestures were predetermined and limited in the current study in order to maintain procedural equivalency across baseline and intervention.

Modeling an increasing set of signs/gestures is not a targeted component of NDBI procedures. Communication partners may imitate gestures (or gesture approximations) performed by the child (Schreibman et al., 2015), and potentially provide a set of predetermined modeled signs/gestures (as in the current study; e.g., Engelstad et al., 2020; Feuerstein & Landa, 2020). However, these imitative interactions are viewed more through the lens of increasing interpersonal synchrony than as a means of supporting unaided communication (Schreibman et al., 2015). Thus, it is not certain that a clinician using NDBI procedures would necessarily continue to model *new* signs/gestures for Lila, as the goal of these interactions would not be specifically to expand her expressive vocabulary. Thus, in a more flexible clinical NDBI setting, it is unlikely that Lila would have had exposure to an increasing array of modeled signs/gestures that reflected her interests – though her gestural symbolic communication may have continued to increase as a result, if she had.

Additionally, several participating children showed some indication of potentially becoming bored with their set of five books after multiple sessions (e.g., selecting each book and scrolling directly to the last page, repeatedly attempting to swipe out of their individual book list on the tablet). Limiting the available books (and, to some extent as a result, the available vocabulary) served to minimize potential confounding variables (e.g., a greater number of books in intervention vs. baseline, books that happened to be more motivating for a participant in one phase vs. the other). However, in a clinical environment, the introduction of additional books and associated new vocabulary would be in response to child preferences and behavior.

Lastly, study procedures took place within a familiar, motivating, and naturalistic routine (shared storybook reading), and in a familiar location (e.g., home, school, therapy center). However, the intervention procedures were only completed within this single activity, at a relatively low intensity, and solely with the researcher. Increasing the intensity per week, length of each session, and/or variety of activities targeted in the intervention may all have positive impacts on children's language and communication growth.

One significant component of the potential for VSD AAC with just-in-time programming is the flexibility and ease with which it can theoretically be integrated into activities and routines across time, location, and communication partner. The relatively substantial language and communication gains observed in this study with just 45 minutes a week of intervention could be significantly increased with more consistent access to the VSD AAC system, paired with effective supports from communication partners (e.g., NDBI strategies, aided AAC input). Importantly, previous research supports the accessibility and ease for communication partners of programming VSDs during communicative interactions (Caron et al., 2016; Holyfield, Caron, & Light, 2019), as well as reported caregiver perceptions in the current study.

Future research is critically needed to address the feasibility of integrating VSD AAC, just-in-time programming, aided AAC input, and NDBI strategies within the daily routines of young children on the autism spectrum with minimal speech, facilitated by their typical communication partners (e.g., parents, teachers, paraprofessionals, SLPs, siblings, peers), and including a greater diversity of participants. Social validity input from caregivers of participating children suggests that training caregivers to implement a version of the current intervention procedures in the context of shared storybook reading is an important immediate next step. However, though caregivers were positive about implementing the intervention themselves, distilling the current study procedures down to a smaller number of key steps would be essential to promote caregiver success and continued use of the strategies across contexts and activities. Additionally, it is critical that relevant activities and communication partners are identified and targeted in a culturally responsive manner, reflecting contexts that are of value to the child and associated stakeholders.

Intervention procedures combining aided AAC and NDBI strategies may be easily adaptable across new activities and environments (e.g., play – Kasari et al., 2014). Contexts such as play could better support investigating the additional intervention component of creating new VSDs just-in-time, along with just-in-time programming new hotspot vocabulary. Previous research suggests that programming VSDs themselves in the context of ongoing communicative interactions is feasible (Drager et al., 2019; Holyfield, Caron, Drager, & Light, 2019) – though this research included adolescents, as opposed to young children. However, the introduction of these intervention procedures into new activities should reflect culturally responsive, family-centered practice, focusing on activities that are valued by the family and meaningful to the child. Future intervention research is needed that builds upon these two dimensions by focusing on communication partner training to promote VSD AAC use with just-in-time programming, paired with NDBI strategies, across activities throughout a child’s day (e.g., family and educational professionals, activities at home and in school).

A critical future direction of this research is exploring ways to promote more equitable access to partner training focusing on NDBI strategy use in the context of supporting children’s aided AAC communication. One option for increasing access to training is to create an online training module.

Recent evidence supports the efficacy of training caregivers online asynchronously to use naturalistic strategies and aided AAC input in the context of book reading to support the communication of their children on the autism spectrum with minimal speech (Wendelken, 2022). The results of Wendelken (2022) suggest both the feasibility and potential effectiveness of translating the current research procedures into an online training for communication partners.

In addition to expanding the current intervention, comparative research is important, in order to ascertain the essential active ingredients within this combination of NDBI procedures and AAC systems that have the potential to maximize language and communication outcomes for young children on the autism spectrum with minimal speech. Specific factors for comparison include the design of AAC systems (e.g., VSD systems vs. traditional grid systems), the type of speech output (e.g., digitized vs. synthesized speech), the inclusion of just-in-time programming vs. only preprogramming AAC vocabulary, and the type of AAC modeling and/or support provided (e.g., only modeling via aided AAC input vs. prompting participants to use aided AAC expressively; unaided modeling of signs/gestures).

Lastly, the results of the current study offer promising evidence that VSD AAC with digitized speech output, just-in-time programming, and aided AAC input within the context of NDBI strategies is effective at promoting language and communication growth for young children on the autism spectrum with minimal speech. However, technological development in AAC has remained limited and slow, especially in contrast with technological innovation more broadly. Furthermore, AAC innovation may often occur without a strong grounding in developmental processes (e.g., linguistic, cognitive, visual, motor). Research and development initiatives are critically needed to expand what is available to support the early language and communication of young children with minimal speech, in order to decrease learning demands, increase appeal, and more effectively support the language trajectory of children who use AAC. Little is known about how children who use AAC learn language. This is a critical component in guiding AAC system design, intervention practices, and future AAC technology development, and is a necessary focus of future research.

Conclusions

Early language skills are a significant predictor of long-term outcomes for individuals on the autism spectrum (Chamak & Bonniau, 2016). However, children with the greatest needs have often been overlooked in the research to date. As a result, clinicians, educators, and families have limited guidance on effective interventions for young children on the autism spectrum with minimal speech. The goal of this research was to enrich the evidence base for this population, aiming to provide families and clinicians with more tools to support early language learning and improve outcomes throughout development. The results of this study demonstrate that the combination of VSD AAC with digitized speech output, just-in-time programming, aided AAC input, and NDBI strategies, can have significant positive effects on the number of communicative turns children take, their vocabulary growth, and the agency children have over their own expressive vocabulary. These results lay the foundation for future research exploring the introduction of NDBI procedures with VSD AAC across a wider set of activities and contexts, and with a range of familiar communication partners, as well as exploring new ways to design AAC technology in order to maximize language and communication outcomes for young children on the autism spectrum with minimal speech.

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Appendix A

IRB Approval Letter

PennState

Office for Research Protections
Human Research Protection Program
Office of The Senior Vice President for Research
The Pennsylvania State University
101 Technology Center
University Park, PA 16802

814-865-1775
irb-orp@psu.edu
research.psu.edu/irb

APPROVAL OF SUBMISSION

Date: October 14, 2022

From: Brittany Wickham, IRB Analyst

To: Lauramarie Pope

Type of Submission:	Initial Study
Short Title:	NDBI + AAC for Children on the Autism Spectrum
Full Title of Study:	Naturalistic Developmental Behavioral Interventions Including AAC for Children on the Autism Spectrum
Principal Investigator:	Lauramarie Pope
Study ID:	STUDY00021203
Submission ID:	STUDY00021203
Funding:	Not Applicable
IND,IDE, or HDE:	Not Applicable
Documents Approved:	• CARS Observation Form.pdf (0.01), Category: Data Collection Instrument • CARS parent questionnaire.pdf (0.01), Category: Data Collection Instrument • GoVisual and Storybook Examples.docx (0.01), Category: Other • Interests Questions.docx (0.01), Category: Data Collection Instrument • MacArthur-Bates Communication Development Inventory.pdf (0.01), Category: Data Collection Instrument • NDBI + AAC Participants with ASD Consent Form 10.13.22.pdf (0.03), Category: Consent Form • NDBI + AAC Protocol 10.13.22.pdf (0.03), Category: IRB Protocol • NDBI + AAC Recruitment Flyer 10.5.22.pptx (0.02), Category: Recruitment Materials • NDBI + AAC Recruitment Letter 10.13.22.docx (0.02), Category: Recruitment Materials • NDBI + AAC Stakeholder Consent Form 10.13.22.pdf (0.06), Category: Consent Form

ID 66

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Office of The Senior Vice President for Research
The Pennsylvania State University
101 Technology Center
University Park, PA 16802

814-865-1775
irb-orp@psu.edu
research.psu.edu/irb

	• Social Validity Questionnaire.docx (0.01), Category: Data Collection Instrument
Review Level:	Expedited

On 10/14/2022, the IRB approved the above-referenced Initial Study. This approval is effective through 10/13/2025 inclusive. You will be required to submit an administrative review form through CATS IRB. You will receive reminders prior to the administrative review form due date.

If an administrative review form is not submitted by the due date, the study will be closed administratively. Attached are stamped approved consent documents. Use copies of these documents to document consent.

In conducting this study, you are required to follow the requirements listed in the HRP-103 – Investigator Manual, which can be found by navigating to the IRB Library within CATS IRB (http://irb.psu.edu). These requirements include, but are not limited to:

- Documenting consent
- Posting a consent form to a federal website, if applicable
- Requesting modification(s)
- Closing a study
- Reporting new information about a study
- Registering an applicable clinical trial
- Maintaining research records

Investigators are responsible for reviewing the History tab of their STUDY in CATS to ensure that any administrative HRPP requests are addressed in a timely manner.

This correspondence should be maintained with your records.

Appendix B

Participant Book Sets

Participant	Book set	Modeled signs/gestures	Preprogrammed hotspots
Henry	**Happy Birthday Cookie Monster**	Bite, open, mix, oh no, ding-dong (doorbell)	Mix, bite (2), oh no, present (3), Cookie Monster, open (2), cake (2)
	It's Time for Bed	Sleep, snuggle, brush (teeth), turn off (lamp), count (to three)	Snuggle (2), pajamas (2), rubber duckie, brush, book, blanket (2), light, sleep (2)
	Pete the Cat Snowy Day	Snowing, shovel, whee, drink, wake up	Snowing (2), hat, sled (2), whee, hot chocolate, friends, shovel (2), snowplow, Pete
	Pete the Cat at the Firehouse	Ring (bell), spray, whee, siren (on fire truck), oh no	Firehouse (2), ring (2), whee, helmet, siren (3), spray (2), Grumpy Toad
	Pete the Cat Builds a Playground	Crash, build, honk, dig, oh no	Swings (2), dump truck (2), crash (2), build (4), playground (2)
Lila	**Happy Birthday Cookie Monster**	Bite, open, mix, oh no, ding-dong (doorbell)	Mix, bite (2), oh no, present (3), Cookie Monster, open (2), cake (2)
	Daniel Tiger Baking Day	Pour, decorate, crack (egg), mix, ouch	Daniel Tiger, pour (2), bowl, mix, dough (2), oven, cookies (2), decorate (2)
	It's Time for Bed	Sleep, snuggle, brush (teeth), turn off (lamp), count (to three)	Snuggle (2), pajamas (2), rubber duckie, brush, book, blanket (2), light, sleep (2)
	Pete the Cat Snowy Day	Snowing, shovel, whee, drink, wake up	Snowing (2), hat, sled (2), whee, hot chocolate, friends, shovel (2), snowplow, Pete
	Pete the Cat Goes to School	Walk, ride (the bus), drink, whee, hi	Lunch (2), bus (2), ride (2), walk, teacher, book, milk, crackers, slide
Lucas	Daniel Tiger Baking Day	Pour, decorate, crack (egg), mix, ouch	Daniel Tiger, pour (2), bowl, mix, dough (2), oven, cookies (2), decorate (2)
	It's Time for Bed	Sleep, snuggle, brush (teeth), turn off (lamp), count (to three)	Snuggle (2), pajamas (2), rubber duckie, brush, book, blanket (2), light, sleep (2)
	Pete the Cat at the Firehouse	Ring (bell), spray, whee, siren (on fire truck), oh no	Firehouse (2), ring (2), whee, helmet, siren (3), spray (2), Grumpy Toad
	Pete the Cat Builds a Playground	Crash, build, honk, dig, oh no	Swings (2), dump truck (2), crash (2), build (4), playground (2)
	Pete the Cat Goes to School	Walk, ride (the bus), drink, whee, hi	Lunch (2), bus (2), ride (2), walk, teacher, book, milk, crackers, slide

Owen	**It's Time for Bed**	Sleep, snuggle, brush (teeth), turn off (lamp), count (to three)	Snuggle (2), pajamas (2), rubber duckie, brush, book, blanket (2), light, sleep (2)
	Pete the Cat Snowy Day	Snowing, shovel, whee, drink, wake up	Snowing (2), hat, sled (2), whee, hot chocolate, friends, shovel (2), snowplow, Pete
	Pete the Cat at the Firehouse	Ring (bell), spray, whee, siren (on fire truck), oh no	Firehouse (2), ring (2), whee, helmet, siren (3), spray (2), Grumpy Toad
	Pete the Cat Builds a Playground	Crash, build, honk, dig, oh no	Swings (2), dump truck (2), crash (2), build (4), playground (2)
	Pete the Cat Goes to School	Walk, ride (the bus), drink, whee, hi	Lunch (2), bus (2), ride (2), walk, teacher, book, milk, crackers, slide
Teagan	**Happy Birthday Cookie Monster**	Bite, open, mix, oh no, ding-dong (doorbell)	Mix, bite (2), oh no, present (3), Cookie Monster, open (2), cake (2)
	Daniel Tiger Baking Day	Pour, decorate, crack (egg), mix, ouch	Daniel Tiger, pour (2), bowl, mix, dough (2), oven, cookies (2), decorate (2)
	It's Time for Bed	Sleep, snuggle, brush (teeth), turn off (lamp), count (to three)	Snuggle (2), pajamas (2), rubber duckie, brush, book, blanket (2), light, sleep (2)
	Pete the Cat Builds a Playground	Crash, build, honk, dig, oh no	Swings (2), dump truck (2), crash (2), build (4), playground (2)
	Pete the Cat Goes to School	Walk, ride (the bus), drink, whee, hi	Lunch (2), bus (2), ride (2), walk, teacher, book, milk, crackers, slide
Ian	**Happy Birthday Cookie Monster**	Bite, open, mix, oh no, ding-dong (doorbell)	Mix, bite (2), oh no, present (3), Cookie Monster, open (2), cake (2)
	Daniel Tiger Baking Day	Pour, decorate, crack (egg), mix, ouch	Daniel Tiger, pour (2), bowl, mix, dough (2), oven, cookies (2), decorate (2)
	It's Time for Bed	Sleep, snuggle, brush (teeth), turn off (lamp), count (to three)	Snuggle (2), pajamas (2), rubber duckie, brush, book, blanket (2), light, sleep (2)
	Pete the Cat Builds a Playground	Crash, build, honk, dig, oh no	Swings (2), dump truck (2), crash (2), build (4), playground (2)
	Pete the Cat Goes to School	Walk, ride (the bus), drink, whee, hi	Lunch (2), bus (2), ride (2), walk, teacher, book, milk, crackers, slide

Note. Most frequently read storybooks for each child are in **bold**. Books read infrequently by participants are in *italics*. These patterns tended to remain consistent across baseline, intervention, and maintenance. See Appendix C for more detailed information regarding modeled signs/gestures, and Appendix D for representations in the storybook pages of preprogrammed hotspots.

Appendix C

Modeled Signs/Gestures for Each Storybook

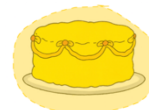
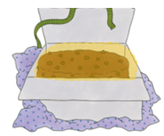
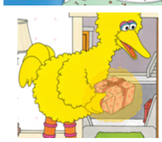
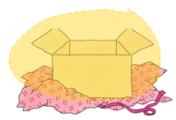
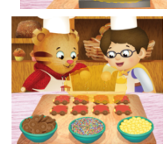
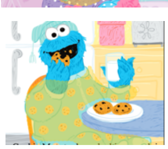
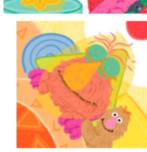
Book (original title*)	Associated vocabulary	Description of sign/gesture
Happy Birthday Cookie Monster	**Bite**	Two hands up to the mouth as if holding food, paired with taking a bite
	Open	Two hands palm down next to each other, one lifts up as if opening the flap of a box
	Mix	Two hands clasped together in a fist, turned in two counterclockwise circles parallel to the ground
	Oh no	Both palms on cheeks with open mouth and eyebrows raised
	Ding-dong (doorbell)	Pointer finger on one hand sticks out forward and then retracts (as if ringing a doorbell)
Daniel Tiger Baking Day	**Pour**	One hand in C shape, tilt sideways (as if pouring out a cup)
	Decorate	Both hands with all fingers in a pincer grasp, alternating small movements forward as hands move up vertically
	Crack (egg)	Two hands facing toward each other with open fingers, quickly rotating down and away (as if cracking an egg)
	Mix	Two hands clasped together in a fist, turned in two counterclockwise circles parallel to the ground
	Ouch	One hand with open fingers, pull up quickly and shake (as if just touching something hot)
It's Time for Bed (All Tucked in on Sesame Street)	**Sleep**	Two hands palms together under side of head, head tilted onto hands (as if sleeping on a pillow)
	Snuggle	Both arms crossed across body as if hugging oneself, rotate side to side
	Brush (teeth)	One hand closed as if holding a toothbrush, back and forth motion next to mouth (as if brushing teeth)
	Turn off (lamp)	One hand in a fist with thumb up, quickly pulled down (as if pulling the chain on a bedside lamp)
	Count (to three)	Raising index, middle, and ring fingers on one hand in succession
Pete the Cat Snowy Day (Pete the Cat Snow Daze)	**Snowing**	Two hands palm down with open fingers, move downward while fluttering fingers
	Shovel	Two hands in fists in a line with palms up (as if holding a shovel), move forward then up and back
	Whee	Two straight arms lifted together from parallel to the ground to above the head
	Drink	One hand in C shape by mouth, tilted towards mouth (as if drinking from a cup)

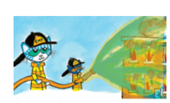
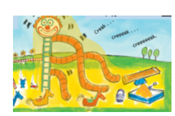
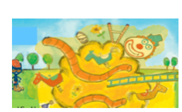
	Wake up	Both arms bent with hands by shoulders, lifted up together over the head
Pete the Cat at the Firehouse (Pete the Cat Firefighter Pete)	**Ring** (bell)	One hand open with palm facing inward, other hand in D shape and hit two times against the open palm, both hands with fingers facing up
	Spray	Two hands in fists in a line with palms up (as if holding a hose), rotate body back and forth (as if spraying a fire hose)
	Whee	Two straight arms lifted together from parallel to the ground to above the head
	Siren (on fire truck)	Two hands with fingers spread and slightly bend, fingers facing up, rotate back and forth three times at wrist
	Oh no	Both palms on cheeks with open mouth and eyebrows raised
Pete the Cat Builds a Playground (Pete the Cat Construction Destruction)	**Crash**	Two straight arms raised above head, lower quickly together towards the ground
	Build	One hand in a fist with thumb up (as if holding a hammer), hinge forward and back at elbow (as if hammering)
	Honk	One hand with open palm and fingers apart, move forward and down and back two times (as if honking on a car horn)
	Dig	Two hands in fists in a line with palms up (as if holding a shovel), move forward then up and back (same as “shovel”)
	Oh no	Both palms on cheeks with open mouth and eyebrows raised
Pete the Cat Goes to School (Pete the Cat Rocking in My School Shoes)	**Walk**	Alternate moving both feet up and down, as if walking in place
	Ride (the bus)	Bounce up and down on chair (as if on a bumpy bus ride)
	Drink	One hand in C shape by mouth, tilted towards mouth (as if drinking from a cup)
	Whee	Two straight arms lifted together from parallel to the ground to above the head
	Hi	One hand up with palm out and fingers apart, move back and forth (as if waving)

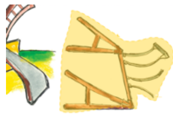
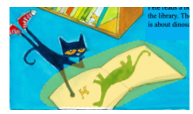
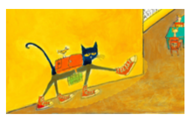
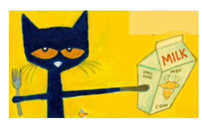
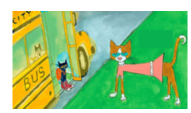
Note. Words in **bold** were the verbs included in the main receptive language measure.
Book titles were adapted to be shorter, as well as better reflect the content of the adapted book text and illustrations (where applicable).
*If applicable

Appendix D

VSD Hotspots Preprogrammed Prior to the First Intervention Session

Book	Vocabulary	Hotspot image	Vocabulary	Hotspot image	Vocabulary	Hotspot image
Happy Birthday Cookie Monster	*Mix*		**Present**		**Cake**	
(7 unique; 4 gestures)	***Bite***		**Present**		***Open***	
	Oh no		Cookie monster		**Cake**	
	Present		***Open***		**Bite**	
Daniel Tiger Baking Day	Daniel Tiger		*Mix*		Cookies	
(8 unique; 3 gestures)	***Pour***		**Dough**		***Decorate***	
	Bowl		**Dough**		***Decorate***	
	Pour		Oven		Cookies	
It's Time for Bed	***Snuggle***		**Pajamas**		Light	
(8 unique; 3 gestures)	**Pajamas**		***Snuggle***		***Sleep***	

	Rubber duckie		Book		Blanket	
	Brush		**Blanket**		***Sleep***	
Pete the Cat Snowy Day	***Snowing***		*Whee*		***Shovel***	
(9 unique; 2 gestures)	Hat		Hot chocolate		**Snowplow**	
	Sled		***Snowing***		***Shovel***	
	Sled		Friends		Pete	
Pete the Cat at the Firehouse	**Firehouse**		***Siren***		***Spray***	
(7 unique; 4 gestures)	***Ring***		***Ring***		Grumpy Toad	
	Whee		***Siren***		**Firehouse**	
	Helmet		***Siren***		**Spray**	
Pete the Cat Builds a Playground	**Swings**		**Dump truck**		Playground	
(5 unique; 2 gestures)	**Dump truck**		***Build***		***Crash***	

	Swings		***Build***		***Build***	
	Crash		***Build***		Playground	
Pete the Cat Goes to School	**Lunch**		Teacher		Crackers	
(9 unique; 2 gestures)	**Bus**		Book		Slide	
	Ride		**Lunch**		***Ride***	
	Walk		Milk		**Bus**	

Note. Words in **bold** were included in the main comprehension measure of spoken words. Words in *italics* were also associated with a book-related sign/gesture.

Appendix E

Predetermined Target Concepts Included in the Main Comprehension Measure of Spoken Language

Book	Nouns	Verbs
Happy Birthday Cookie Monster	Cake, present	Bite, open
Daniel Tiger Baking Day	Bowl, dough	Pour, decorate
It’s Time for Bed	Blanket, pajamas	Sleep, snuggle
Pete the Cat Snowy Day	Sled, snowplow	Snowing, shovel
Pete the Cat at the Firehouse	Firehouse, siren	Ring, spray
Pete the Cat Builds a Playground	Swings, dump truck	Build, crash
Pete the Cat Goes to School	Bus, lunch	Walk, ride

Appendix F

Format and Example Page from the Main Comprehension Measure of Spoken Language

Note: Clockwise from top left – snowing, crash, bite, build

Four pictures (the target and three foils of the same part of speech, represented using illustrations from that participant's storybooks) were presented on an iPad for each target concept. At the beginning of the task, the participant was instructed to look at all the pictures and touch the picture that matched the word the researcher said. The researcher then spoke the target word aloud for each trial and waiting up to 10 seconds for the participant to respond. The researcher offered general praise and encouragement, but no feedback on the accuracy of response. Owen completed this task with identical procedures, but using paper-based materials.

Appendix G

Format and Example Pages from the Individualized Post-Hoc Comprehension Measure of Spoken Language

Figure **G-1**: Target concepts represented using book illustrations. Clockwise from top left – oh no, sleep, ring, brush.

Figure **G-2**: Target concepts represented using digital photographs. Clockwise from top left – oh no, sleep, ring, brush.

Procedures were identical to the main comprehension measure of spoken language. All participants completed the task with the book illustrations first, followed by the digital photographs.

Appendix H

Baseline Procedural Fidelity Checklist

Researcher has an equal number of questions and comments (3c., differences of 2 or less: + or /):

Each book page:

1. Read the book page (may include a gesture/action) (+ or /)	
2. Pause (3 seconds or until a communication attempt) (+ or /)	
3a. Communication attempt (go here ***anytime*** the participant attempts communication *related to the activity*) – **Respond contingently**	3b. No communication attempt (*only* go here if the participant does **not** attempt communication independently on a book page) – Complete the following **prompting hierarchy**
4. Label/repeat participant's communication attempt (+ or /) (and imitate any book/related gestures)	3c. Researcher makes a comment or asks a question ("q", "c", or /)
	3d. Pause (3 seconds or until a communication attempt) (+ or /)
5. Expand on participant's communication attempt (+ or /)	3e. Gestural prompt to book (+ or /)
	3f. Pause (3 seconds or until a communication attempt) (+ or /)
6. Pause (3 seconds or until a communication attempt) (+ or /)	3g. Model (i.e., repeat comment or answer question) (+ or /)
	3h. Pause (3 seconds or until a communication attempt) (+ or /)
7. Read next page of book (go to 1.)	3i. Read next page of book (go to 1.)

The research assistant continued to complete the baseline procedural fidelity checklist for every page read by the researcher until the entire 10-minute sample was coded. Number of pages read varied widely across sessions within and between participants.

Appendix I

Intervention Procedural Fidelity Checklist

Researcher has an equal number of questions and comments (3c., differences of 2 or less):

Each book page:

1. Read the book page (may include a gesture/action) (+ or /) **+ activate at least one hotspot on tablet**	
2. Pause (3 seconds or until a communication attempt) (+ or /)	
3a. Communication attempt (go here ***<u>anytime</u>*** the participant attempts communication *related to the activity*) – **Respond contingently**	3b. No communication attempt (*only* go here if the participant does **not** attempt communication independently on a book page) – Complete the following **prompting hierarchy**
4. Label/repeat participant's communication attempt (+ or /) (and imitate any book/related gestures) - **Label/repeat verbally** **- Activate hotspot (program new hotspot if necessary)** **(e.g., "Mix!" + [MIX])**	3c. Researcher makes a comment or asks a question ("q", "c", or /) **(may or may not include hotspot activation)**
	3d. Pause (3 seconds or until a communication attempt) (+ or /)
5. Expand on participant's communication attempt (+ or /) **- Expand verbally** **- Activate relevant hotspot(s)** **(e.g., "Daniel mixes!" + [MIX])**	3e. Gestural prompt to book (+ or /)
	3f. Pause (3 seconds or until a communication attempt) (+ or /)
6. Pause (3 seconds or until a communication attempt) (+ or /)	3g. Model (i.e., repeat comment or answer question) (+ or /) **(may or may not include hotspot activation)**
	3h. Pause (3 seconds or until a communication attempt) (+ or /)
7. Read next page of book (go to 1.)	3i. Read next page of book (go to 1.)

The research assistant continued to complete the intervention procedural fidelity checklist for every page read by the researcher until the entire 10-minute sample was coded. Number of pages read varied widely across sessions within and between participants.

Appendix J

Caregiver Social Validity Questionnaire

Video 1

Questionnaire Item	Responses					
	Unsure	Strongly Disagree 1	2	3	4	Strongly Agree 5
The activity was effective at supporting the participant's communication.	?	1	2	3	4	5
The participant could participate independently in the activity.	?	1	2	3	4	5
The activity seems feasible for a parent or teacher to do with the participant.	?	1	2	3	4	5
The participant seemed to enjoy the activity.	?	1	2	3	4	5
I would recommend this activity to others.	?	1	2	3	4	5

Is there anything else you would like to add?

Video 2

Questionnaire Item	Responses					
	Unsure	Strongly Disagree 1	2	3	4	Strongly Agree 5
The activity was effective at supporting the participant's communication.	?	1	2	3	4	5
The participant could participate independently in the activity.	?	1	2	3	4	5
The activity seems feasible for a parent or teacher to do with the participant.	?	1	2	3	4	5
The participant seemed to enjoy the activity.	?	1	2	3	4	5
I would recommend this activity to others.	?	1	2	3	4	5

Is there anything else you would like to add?

Please consider both videos that you just watched and circle the **ONE** video that you think best answers each question.

1. In which video did the participant communicate more effectively?

   Video 1 Video 2

2. In which video did the participant participate more actively?

   Video 1 Video 2

3. In which video did the participant appear to enjoy the activity more?

   Video 1 Video 2

Is there anything else you would like to add?

Appendix K

All Concepts Used Expressively by Participants Across all Study Phases

Table **K-1**: Henry – all concepts used expressively across baseline, intervention, and maintenance.

Concept	Part of speech	Speech	Gesture	Aided AAC	JIT only	Total*	BL	Int	Maint
Abby	Noun			4	x	4		x	
Bert	Noun			17	x	17		x	x
Big Bird	Noun			2	x	2		x	x
Bite	Verb			1		1		x	
Blanket	Noun			2		2		x	x
Book	Noun			2		2		x	x
Brush (teeth)	Verb		1	3		4	x	x	
Cookie Monster	Noun			16		16		x	x
Elmo	Noun			17	x	17		x	x
Ernie	Noun			9	x	9		x	x
Grover	Noun			6	x	6		x	x
Helmet	Noun			1		1			x
Light	Noun			2		2		x	
Mix	Verb		1			1		x	
Oh no	Interjection	4	2	18		24		x	x
Pajamas	Noun			2		2		x	x
Pete	Noun			3	x	3		x	
Present	Noun			1		1		x	
Ring (bell)	Verb		2	2		4	x	x	
Robe	Noun			3	x	3		x	
School bus	Noun			1	x	1			x
Sleep	Verb			16		16		x	x
Snuggle	Verb			2		2		x	
Teddy bear	Noun			1	x	1		x	
Teeth	Noun	2		1	x	3		x	
The Count	Noun			3	x	3		x	
Toothbrushes	Noun			1	x	1		x	
Zoe	Noun			7	x	7		x	x
Total	28	6	6	143	14	155	2	26	14
Noun	21								
Verb	6								
Other	1								
Word combinations			**Mode**						
Bert + teeth			Aided AAC						

Note: JIT Only = concepts that were programmed just-in-time, and only available to the participant within the aided AAC system as a result of just-in-time programming; BL = baseline; Int = intervention; Maint = maintenance

*Total frequency of communication for that concept, across all modalities and phases

Table **K-2**: Lila – All concepts used expressively across baseline, intervention, and maintenance.

Concept	Part of speech	Speech	Gesture	Aided AAC	JIT only	Total*	BL	Int	Maint
All done	Descriptor	1	1			2	x		
All gone	Descriptor			12	x	12		x	
Backpack	Noun			1	x	1		x	
Baaa	Onomatopoeia	2				2	x		
Baker	Noun			5	x	5		x	x
Baking	Verb			1	x	1		x	
Bert	Noun			2	x	2			x
Big Bird	Noun			1	x	1		x	
Birthday	Noun			3	x	3		x	
Bite	Verb		6	4		10	x	x	x
Bowl	Noun	1		4		5		x	x
Brush (teeth)	Verb		3			3	x		
Bubble	Noun	2				2		x	
Cake	Noun			4		4		x	
Candies	Noun			2	x	2		x	
Chocolate chips	Noun			2	x	2		x	
Circle	Noun			1	x	1		x	
Cookie Monster	Noun	1		27		28		x	x
Cookies	Noun			1	x	1			x
Crack (egg)	Verb		3			3	x		
Daniel Tiger	Noun			12		12		x	x
Decorate	Verb			1		1		x	
Ding-dong	Noun		1			1	x		
Doll	Noun			1	x	1		x	
Door	Noun			3	x	3		x	
Dough	Noun			1		1		x	
Eggs	Noun			1	x	1		x	
Elmo	Noun			1	x	1		x	
Hat	Noun		2	1	x	3		x	
I don't know	Phrase	1				1		x	
Icing	Noun			1	x	1		x	
Kiss	Verb		2			2	x		
Lunch	Noun			1		1		x	
Milk	Noun			2	x	2		x	
Mix	Verb		2	2		4	x	x	
Oh no	Interjection		19	23		42	x	x	x
One	Noun		4			4	x		
Open	Verb		2	4		6	x	x	
Oven	Noun			1		1		x	
Pajamas	Noun			2		2		x	
Pete	Noun			3	x	3		x	
Present	Noun			8		8		x	x
Prince Wednesday	Noun			3	x	3		x	
Roll (dough)	Verb		1			1	x		
Rubber ducky	Noun			3		3		x	

Shapes	Noun			4	x	4		x	
Sled	Noun			1		1		x	
Sleep	Verb		2	1		3	x	x	
Slide	Noun			1		1		x	
Snuggle	Verb		8	2		10	x	x	
Sprinkles	Noun			2	x	2		x	x
Square	Noun			3	x	3		x	
Star	Noun			3	x	3		x	
Teacher	Noun			1		1		x	
The Count	Noun			5	x	5		x	
Three	Noun		3			3	x		
Triangle	Noun			3	x	3		x	
Turn off (light)	Verb		1			1	x		
Two	Noun	2	2			4	x		
Walk	Verb			1		1		x	
White chocolate	Noun			4	x	4		x	x
Total	61	10	62	177	27	249	17	48	13
Noun	43								
Verb	13								
Other	5								

Word combinations	**Mode**
Bite + Cookie Monster (3x)	Aided AAC
Cookie Monster + present	Aided AAC
Sprinkles + white chocolate + chocolate chips	Aided AAC
Oh no + all gone	Aided AAC

Note: JIT Only = concepts that were programmed just-in-time, and only available to the participant within the aided AAC system as a result of just-in-time programming; BL = baseline; Int = intervention; Maint = maintenance

*Total frequency of communication for that concept, across all modalities and phases

Table **K-3**: Lucas – all concepts used expressively across baseline, intervention, and maintenance.

Concept	Part of speech	Speech	Gesture	Aided AAC	JIT only	Total*	BL	Int	Maint
Abby	Noun			4	x	4		x	x
Baby David	Noun			18	x	18		x	x
Brush (teeth)	Verb		1	6		7	x		
Decorate	Verb		1			1	x		
Doll	Noun			5		5			x
Dump truck	Noun			1		1			x
Elmo	Noun			17	x	17		x	
Grover	Noun			3	x	3		x	
Me	Pronoun		1			1		x	
Oh no	Interjection		6	116		122	x		x
Pajamas	Noun			11		11		x	
Pillow	Noun			1	x	1		x	
Playground	Noun			2		2		x	
Ride (bus)	Verb			1		1		x	
Sandbox	Noun			1	x	1			x
Sleep	Verb	7	3	39		49	x	x	x
Snuggle	Verb		8	12		20	x	x	x
Swings	Noun			7		7		x	x
Turn off (light)	Verb		1			1	x		
Wake up	Verb		1			1	x		
Whee	Interjection		9	67		76	x	x	
Total	21	7	31	311	7	349	8	13	9
Noun	11								
Verb	7								
Other	3								

Word combinations	**Mode**
Sleep + Baby David	Aided AAC
Swings + oh no	Aided AAC
Snuggle + Abby (2)	Aided AAC
Snuggle + Baby David	Aided AAC
Abby + doll	Aided AAC

Note: JIT Only = concepts that were programmed just-in-time, and only available to the participant within the aided AAC system as a result of just-in-time programming; BL = baseline; Int = intervention; Maint = maintenance

*Total frequency of communication for that concept, across all modalities and phases

Table **K-4**: Owen – all concepts used expressively across baseline and intervention.

Concept	**Part of speech**	**Speech**	**Gesture**	**Aided AAC**	**JIT only**	**Total***	**BL**	**Int**
Big Bird	Noun			2	x	1		x
Blanket	Noun			2				
Build	Verb			1		1		x
Cookie Monster	Noun			1				
Elmo	Noun			3	x	3		x
Fire jacket	Noun			1	x			
Firefighter	Noun			1	x			
Firehouse	Noun			5				x
Firetruck	Noun			4	x	1		x
Flames	Noun			1	x			x
I don't know	Phrase	2				1		x
Lunch	Noun			1		1		x
Mom	Noun			1	x	1		x
Oh no	Interjection	1				1		x
Pajamas	Noun			1		1		x
Playground	Noun			1		1		x
Ring (bell)	Verb		56	2		39	x	x
School bus	Noun			5				x
Siren	Noun		6	2		3		x
Sleep	Verb			2		1		x
Snuggle	Verb		1			1		x
Whee	Interjection	1	1			2		x
Total	22	4	64	36	7	104	1	18
Noun	15							
Verb	4							
Other	3							

Word combinations	**Mode**
Firehouse + school bus	Aided AAC

Note: JIT Only = concepts that were programmed just-in-time, and only available to the participant within the aided AAC system as a result of just-in-time programming; BL = baseline; Int = intervention; Maint = maintenance

*Total frequency of communication for that concept, across all modalities and phases

Table **K-5**: Teagan – concepts used expressively across baseline and intervention.

Concept	Part of speech	Speech	Gesture	Aided AAC	JIT only	Total*	BL	Int
Bert	Noun			1	x			x
Big Bird	Noun			1	x			x
Bite	Verb			1				x
Brush (teeth)	Verb		3				x	
Cookie Monster	Noun			2				x
Door	Noun	1						x
Eat	Verb	1					x	
Elmo	Noun			8	x			x
Ernie	Noun			1	x			x
Go	Verb	1					x	
Grover	Noun			2	x			x
Hi	Interjection			1	x			x
More	Descriptor		1			1	x	
Oh no	Interjection		1			2		x
Pajamas	Noun			6		2		x
Sheep	Noun	1				1	x	
Sleep	Verb	2	51	17		29	x	x
Snuggle	Verb	1	1			3	x	x
Turn off (light)	Verb			1		1		x
Yeah	Interjection	2				1	x	
Total	20	9	57	41	6	107	8	14
Noun	9							
Verb	7							
Other	4							

Word combinations	**Mode**
Grover + Ernie	Aided AAC
Grover + Big Bird	Aided AAC
Cookie Monster + bite	Aided AAC

Note: JIT Only = concepts that were programmed just-in-time, and only available to the participant within the aided AAC system as a result of just-in-time programming; BL = baseline; Int = intervention; Maint = maintenance

*Total frequency of communication for that concept, across all modalities and phases

Table **K-6**: Ian – all concepts used expressively across baseline and intervention.

Concept	Part of speech	Speech	Gesture	Aided AAC	JIT only	Total*	BL	Int
Big Bird	Noun			1	x	1		x
Bite	Verb		1	48		49	x	x
Blanket	Noun			2		2		x
Book	Noun			1		1		x
Bowl	Noun	1		1		2	x	x
Boots	Noun			1	x	1		x
Brush (teeth)	Verb			2		2		x
Build	Verb			1		1		x
Bus	Noun			9	x	9		x
Cake	Noun			28		28		x
Cookie Monster	Noun			17		17		x
Cookies	Noun			6		6		x
Daniel Tiger	Noun			4		4		x
Decorate	Verb			1	x	1		x
Door	Noun			52		52		x
Dough	Noun			3		3		x
Fire jacket	Noun			6	x	6		x
Firehouse	Noun			7		7		x
Grover	Noun			4	x	4		x
Helmet	Noun			4		4		x
Light	Noun			1		1		x
Mix	Verb			12		12		x
Oh no	Interjection		1	2		3	x	x
Open	Verb			13		13		x
Oven	Noun			13		13		x
Pajamas	Noun			2		2		x
Playground	Noun			1		1		x
Pour	Verb			7		7		x
Present	Noun			9		9		x
Prince Wednesday	Noun			2		2		x
Ring	Verb			1		1		x
Siren	Noun			1		1		x
Snuggle	Verb			1		1		x
Swings	Noun			3		3		x
Whee	Interjection			1		1		x
Yeah	Interjection	2				1	x	x
Total	36	3	2	282	6	287	4	36
Noun	23							
Verb	9							
Other	3							

Word combinations	Mode
Grover + present	Aided AAC
Door + Grover + door	Aided AAC
Grover + door	Aided AAC
Cake + Cookie Monster	Aided AAC

Bus + firehouse	Aided AAC
Cake + open + cake	Aided AAC
Open + cake	Aided AAC

Note: JIT Only = concepts that were programmed just-in-time, and only available to the participant within the aided AAC system as a result of just-in-time programming; BL = baseline; Int = intervention; Maint = maintenance

*Total frequency of communication for that concept, across all modalities and phases

VITA

Lauramarie Pope

<u>EDUCATION</u>

Doctor of Philosophy, Communication Sciences & Disorders 2023
The Pennsylvania State University, University Park, PA (Expected)

Master of Science, Communication Sciences & Disorders 2018
The Pennsylvania State University, University Park, PA

Master of Arts, Anthropology 2015
The Pennsylvania State University, University Park, PA

Bachelor of Arts, Psychology; American Literature and Culture 2009
University of California, Los Angeles, Los Angeles, CA

<u>EXTERNALLY FUNDED GRANTS</u>

American Speech-Language-Hearing Foundation 2022-2023
Student Research Grant in Early Childhood Language Development

Organization for Autism Research 2021-2022
Graduate Research Grant

<u>SELECTED PUBLICATIONS AND PRESENTATIONS</u>

Holyfield, C., Pope, L., Light, J., Jakobs, E., Laubscher, E., McNaughton, D., & Pfaff, O. (2023). Effects of an augmentative and alternative communication technology decoding feature on single-word reading by individuals with down syndrome and limited functional speech. *American Journal of Speech-Language Pathology*, *32*(3), 1195-1211.

Pope, L., Light, J., & Franklin, A. (2022). Black children with developmental disabilities receive less augmentative and alternative communication intervention than their white peers: Preliminary evidence of racial disparities from a secondary data analysis. *American Journal of Speech-Language Pathology*, *31*(5), 2159-2174.

Pope, L., & Light, J. (2022, November). *Comparison of text vs. picture symbol AAC systems to maximize outcomes for children with ASD* [Technical session accepted for presentation]. American Speech-Language-Hearing Association Convention in New Orleans, LA.

Pope, L., Light, J., & Laubscher (2022, November). *Naturalistic developmental behavioral interventions and AAC for children with ASD: A systematic Review* [Poster accepted for presentation]. American Speech-Language-Hearing Association Convention in New Orleans, LA.

Pope, L. & Light, J. (2021, November). *Preliminary evidence for racial disparities in augmentative and alternative communication services* [Poster presentation]. American Speech-Language-Hearing Association Convention in Washington, DC.

Pope, L., Holyfield, C., Light, J., & McNaughton, D. (2018, March). *Supporting literacy in communication: Visual scene displays with dynamic text* [Technical session]. Pennsylvania Speech-Language Hearing Association Convention in Pittsburgh, PA.