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Effects of an AAC Technology Decoding Feature on Single-Word Reading by Individuals with Down Syndrome and Limited Functional Speech

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Abstract

Purpose: Literacy skills are foundational to participation in adolescent and adult life and decoding skills (i.e., sounding out to read words) are critical to literacy learning. Literacy also increases communication options for individuals with developmental disabilities who use augmentative and alternative communication (AAC). Yet, current AAC technologies are limited in their support of literacy development (especially decoding skills) for the individuals with developmental disabilities who require them. The purpose of the current study was to conduct a preliminary evaluation of a new AAC feature designed to support decoding skills.

Method: Three individuals who had limited functional speech and limited literacy skills, specifically two adolescents and one young adult with Down syndrome, participated in the study. The study used a single-subject, multiple probe across participants design.

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Results: All three participants demonstrated increases in reading performance, including decoding of novel words. High variability in performance was observed, however, and no participant reached reading mastery. Still, analysis reveals that for all participants, interacting using the new app feature increased reading.

Conclusion: These results offer preliminary evidence that an AAC technology feature that provides models of decoding (upon selection of AAC picture symbols) can support individuals with Down syndrome in building decoding skills. While not intended to replace instruction, this initial study offers initial evidence in its efficacy as a supplemental avenue for supporting literacy in individuals with developmental disabilities who use AAC.

Keywords

Augmentative and alternative communication; Developmental disability; Literacy

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Full participation in adolescent and adult life means engaging meaningfully in social, academic, and vocational contexts (Holyfield & Caron, 2019; McNaughton & Kennedy, 2010). Increasingly, engagement in such contexts is achieved in no small part by applying literacy skills. For instance, many social encounters now occur over text or text-based social media platforms, and educational success relies on reading and writing skills. Therefore, functional literacy is crucial for all adolescents and adults to be fully engaged in this major life period, beginning at age 10 and extending throughout the remainder of one's life. Functional literacy refers to meaningful literacy skills that can be applied to everyday life, promote participation, and allow for social connection (Keefe & Copeland, 2011).

For adolescents and adults who have limited functional speech due to Down syndrome, the importance of literacy is further elevated. Augmentative and alternative communication technologies provide supports for effective communication for adolescents and adults with Down syndrome despite limitations in speech (e.g., Light, McNaughton et al., 2019; McNaughton et al., 2021). Using a keyboard option on those technologies allows for fully generative communication unencumbered by the need to rely on preprogrammed vocabulary.

Unfortunately, most adolescents and adults with Down syndrome and limited speech do not have functional literacy skills (Light & McNaughton, 2013). Furthermore, they have reached an age where access to instructional experts and educational opportunities to develop literacy skills may be limited (McNaughton et al., 2021). For example, most literacy instruction is designed for younger individuals, and many adolescents and adults are past the age of attending school where literacy instruction typically occurs. Despite limited opportunities to do so, research shows that individuals with intellectual and developmental disabilities who do not have functional speech can develop foundational literacy skills in adolescence and adulthood (Yorke et al., 2021).

In recent years, AAC researchers have advanced the science of effective AAC technology design (Light, Wilkinson et al., 2019). In doing so, researchers have provided insights into specific features that can improve outcomes for users rather than simply completing post hoc evaluations of apps designed based on the status quo or the instincts of the creators. This approach has yielded evidence-based innovations in AAC technology. As a result, the scope of what AAC technology can support has expanded.

Specific to literacy, an AAC technology transition to literacy (T2L) feature was recently developed for visual scene display (VSD) and grid display apps to support the recognition of single words, or sight word reading[1] (Light et al., 2014). The feature uses motion and size growth to draw visual attention to text representations of words (Jagaroo & Wilkinson, 2008), thus supporting orthographic processing (Adams, 1994); the text is then paired with speech output, thus supporting phonological processing of the words (Adams, 1994). The feature is linked to the picture symbols (i.e., color photo or line drawing representations) in the AAC technology, thus supporting meaning processing (Adams, 1994).

Empirical evidence revealed the efficacy of the T2L sight word feature in increasing single word reading (Light, McNaughton et al., 2019). Specifically, a series of studies demonstrated that the feature supported literacy gains for adults with Down syndrome and other intellectual and developmental disabilities (Holyfield et al., 2020) in addition to other groups of individuals, including: adolescents with autism spectrum disorder (ASD; Caron et al., 2021) and cerebral palsy (e.g., Mandak, Light, & McNaughton, 2020); school-age individuals with ASD (Caron et al., 2018), severe disabilities (Caron et al., 2020), and multiple disabilities (Holyfield et al., 2019); and young children with developmental disabilities (Boyle et al., 2021) and ASD (Mandak et al., 2019). It is important to note that this feature is not intended to replace literacy instruction; rather it is intended to supplement instruction by providing additional exposure to literacy learning opportunities within the individual's AAC application.

Sight word recognition is a valuable skill that can be applied by adolescents and adults with Down syndrome to support their participation and communication. Still, sight word recognition on its own does not lead to full functional literacy. Functional literacy demands the ability to sound out, or decode, novel words. To support fully functional literacy, more research-based feature development was required.

Therefore, AAC researchers developed a new T2L technology feature, compatible with either visual scene display (VSD) or grid-based systems, with the goal of expanding the reach of AAC technology by providing models of decoding (Light, McNaughton, & Jakobs, 2019). The feature uses many of the same principles of the sight word feature including motion, text enlargement, and the pairing of orthographic and phonological representations of words. Except, this decoding feature uses luminance to drive visual attention to each individual letter (Turatto & Galfano, 2000). The feature first pairs graphemes with their corresponding phonemes using luminance to highlight each letter in turn while producing that letter sound via voice output, and then the feature illuminates the entire word and speaks the whole word (see Figure 1); thus, the feature provides models of decoding for users. For demonstration of the T2L decoding feature, please see https://rerc-aac.psu.edu/design-of-t2l-decoding-feature/. As with the sight word feature, this new decoding feature is not intended

[1]This feature for supporting sight word reading is currently available on a number of commercially available AAC technologies, including the SnapScene app from Tobii Dynavox, the GoVisual from Attainment, the EasyVSD from Invotek, and NovaChat devices from Saltillo.

to replace literacy instruction; rather it is intended to provide additional exposure to models of decoding to supplement instruction. Importantly, this technology feature is designed with the goal of fully integrating the models of decoding (provided by the T2L decoding feature option) within any AAC application or software people with developmental disabilities use to communicate throughout their daily lives.

The Current Study

The current study explored the efficacy of an AAC app containing the newly developed T2L decoding feature (the independent variable) on the single-word reading skills (the dependent variable) of adolescents and adults with Down syndrome. The primary research question posed in this study was: What is the effect of exposure to the AAC app with the decoding feature during motivating interactions on the single word reading performance of participants with Down syndrome and limited functional speech? It is impossible to know with certainty the inner processes used to read a word; learners might use either sight word recognition skills or decoding skills to read single words. However, if an intervention causes increases in reading that includes increases in reading novel words (i.e., words not included in intervention), decoding skills must be being applied with increased success. Therefore, the dependent variable in this study was the participants' accuracy reading single words on a probe task that included both words that were modeled in the T2L decoding app as well as novel words that were not previously known and were not modeled within the AAC app during intervention. A second research question specifically considered the participants' performance with the novel words: What is the effect of the AAC app with the T2L decoding feature on the participants' accuracy applying decoding skills to novel words?

We hypothesized that, because the decoding feature was designed with a strong empirical and theoretical foundation for supporting decoding, participants would improve their reading performance following their use of the app. However, it is challenging to learn to decode so we hypothesized there would be a significant lag in time between the participants beginning to use the app and increases in their decoding skills. Further, we hypothesized that participants would improve their reading of the words modeled by the decoding feature during intervention before they demonstrated improvements in reading novel words since they could draw on both decoding skills and recognition skills to read the former words given their repeated exposure to models of decoding these words via the AAC feature during intervention.

Method

Institutional review board approval was obtained prior to the start of the study. Approval occurred at both universities with which researchers were affiliated.

Research Design

To explore the research questions, a single-subject multiple probe design was implemented (Horner & Baer, 1978). The independent variable was the AAC app technology with the T2L decoding feature. As noted earlier, the main dependent variable was the participants' performance reading single words, demonstrated through accurate selection of the printed word out of a field of 6 choices upon presentation of a photo depicting the target word. The design staggered the start of intervention across participants in one leg of three participants to establish experimental control. There were two phases in the study design: baseline and intervention. Unfortunately due to scheduling constraints, the study was terminated before a maintenance phase could be completed (see the section on Limitations for further discussion of this limitation). Because of the COVID pandemic, the study was designed to be conducted remotely via Zoom. Remote participation was designed to resemble in-person interactions as much as possible despite the session modality being virtual.

Since the purpose of this study was to evaluate the efficacy of the decoding feature, all phase shift decision making was based on participants' performance decoding the novel words. No phase shifts occurred without the completion of at least five measurement probes in that phase in accordance with single-subject methodology standards (Kratochwill et al., 2013). In addition to the minimum of five probes, preset criteria were used to determine a shift for each participant from baseline to intervention. First, participants must have demonstrated at least two consecutive sessions of flat or downward sloping performance decoding novel words, indicating a stable baseline. Second, for Jay and Ben, the participant who started intervention immediately before them must have demonstrated an intervention effect. An intervention effect was defined as two consecutive sessions with performance decoding novel words above the participants' highest baseline performance. After an intervention effect was observed and the next participant began intervention, probes occurred only after every 3 intervention sessions with the app in an effort to reduce the demands of repeated probe testing. The study had to be ended before participants demonstrated performance mastery in the intervention phase due to scheduling conflicts; however, the intervention phase was not ended for any participant until they completed at least as many intervention sessions as baseline sessions and demonstrated performance above the participant's highest baseline performance across at least two consecutive sessions.

Participants

Recruitment of participants occurred through sharing an informational flyer with professionals who worked with individuals with Down syndrome. These professionals subsequently shared the flyer with potential families, and interested families contacted the research team about participation. Then, the research team and families met using videoconferencing software to discuss the study, and interested families returned a signed consent form via email.

All three families who met with the researchers returned a consent form and the family member with Down syndrome participated. All participants met the following inclusion criteria: (a) had a diagnosis of Down syndrome; (b) were at least 10 years of age or older at the start of the study, marking the beginning of early adolescence according to the World Health Organization; (c) had speech that was not meeting communication needs per parent report; (d) had functional hearing, motor, and vision required to participate in computer activities using a mouse, per parent report and pre-screening; (e) had knowledge of at least 6 letter sound correspondences, per pre-screening; (f) had no more than emerging decoding skills, demonstrating less than 20% accuracy in decoding cvc words, per pre-screening; and (g) had regular and reliable computer and internet access.

The three participants – Kora, Jay, and Ben – ranged in age from early adolescence to young adulthood. All three participants lived at home with their parents; Jay and Ben also had siblings living at home. Kora had previously finished school but was enrolled in vocational and social day programs. Jay and Ben were enrolled in special education programs within their community schools. None of the participants attended programs with a strong focus on literacy, according to parent report. All participants were reported to have hearing and vision within normal limits. Through observation during pre-screening performance, it was confirmed that all participants had the hearing and vision to participate in the study. All participants relied primarily on speech to communicate, though their speech was limited in effectiveness and alternate communication forms were also common for each participant. All participants had experience with aided AAC, though not with a VSD-based app like that used in the current study except for Kora. However, high-tech VSDs are highly intuitive (Holyfield et al., 2017); all participants used the app with ease (remotely) to interact throughout the study.

Prior to the study, participants completed a pre-screening to evaluate their knowledge of letter sound correspondences. They were also tested to determine their knowledge of the concepts underlying the target words in the study by presenting the target words orally and asking them to select a photo representing the concept from a field of four options. Any concepts unknown by a participant were taught prior to the start of the study. For one participant, Kora, who had limited letter sound correspondence knowledge, the letter sounds used in the study were taught over a few brief sessions prior to the study's start until she attained 80% accuracy in one independent practice session. Sessions followed previously established procedures for teaching and testing letter sounds (Caron et al., 2022). The study began immediately for Kora after this brief letter sound correspondence teaching; no follow up on letter sound teaching or testing occurred. Please see Table 1 for more detailed information about the participating individuals and results of the letter sound correspondence pre-screening.

Materials

The study included the following materials: lists of consonant-vowel-consonant (cvc) words; the AAC app with the T2L decoding feature; adapted books to provide a meaningful context during intervention for exposure to models of decoding provided by the AAC app feature; and probe materials to measure reading performance.

Word Lists—A bank of cvc words was identified by reviewing letter sounds familiar across participants (i.e., a, c, i, p, m, n, o, t) and then generating words that were most likely to be meaningful to participants that also contained the known letter sounds. Selected cvc words were mostly imageable nouns, though some more abstract concepts (e.g., "not") were included due to the limits of using fewer letter sounds. From this initial bank of consonant-vowel-consonant words, triplets of words were created by selecting three minimal pairs when possible or, when not possible, three words sharing a common feature (e.g., same initial letter sound). Once eight such word triplets were created, each word per triplet was randomly assigned to one of three word lists: (1) pin, tip, mop, cap, mac, not, pan, cat; (2) map, pit, pot, pat, cop, tap, top, tan; and (3) mat, man, can, pop, cot, nap, tin, pic.

For each of the participants, one of the word lists was designated as *novel* words (i.e., the words on the novel word list were never modeled by the decoding feature in the AAC app during intervention but these words were tested in the probes); one of the word lists was designated as *programmed* words (i.e., the words on the programmed list were modeled by the decoding feature within the AAC app during each intervention session and were tested in the probes); and one of the word lists was designated as *programmed but not tested* words (i.e., the words on this list were regularly modeled by the decoding feature in the AAC app during intervention but were not tested on the probes). The *novel* words allowed for testing of the participants' application of decoding skills to new words without any potential confound from prior exposure to the words and recognition learning through the AAC app. The *programmed* words were regularly modeled in the AAC app by the decoding feature and allowed for testing words directly that were modeled by the app to see if learning occurred, either through decoding or recognition. The *programmed but not tested* words were included in the AAC app and provided exposure to a greater number of models to support generalized acquisition of decoding skills; however, these words were not probed in the study to protect against over-testing. The assignment of the word lists was counterbalanced across participants to control for any confounds from list effects.

AAC Application with the T2L Decoding Feature—In intervention, each participant interacted using a visual scene display (VSD) AAC app with color photos representing the words in the *programmed* and *programmed but not tested* word lists. The app contained the T2L feature designed to support literacy learning by modeling decoding (see Figure 1). While the long-term goal of the researchers is to determine the efficacy of a decoding AAC feature that can be integrated across a range of AAC applications (including VSDs and grid displays) used by individuals with developmental disabilities throughout their daily communication lives, this study evaluated a beta version of the T2L decoding feature (developed for research purposes) within a VSD app. In order to promote decoding, the T2L feature provided a model of decoding upon selection of a target picture symbol from the VSD, using: (1) dynamic movement of text and text enlargement to capture visual attention to the text; (2) sequential illumination of individual letters to drive visual attention to the letters within the word; (3) pairing of each letter with its corresponding sound to promote phonological coding; (4) and luminance of the entire word and pairing with speech output of the entire word to support sound blending (Light, McNaughton, & Jakobs, 2019). The entire model of decoding a single word from beginning (i.e., initial selection of the picture symbol and appearance of the text) to end (i.e., final disappearance of the text) took 11.25 seconds for words with three sounds such as the cvc words from the current study.

The AAC app was programmed for each participant with the words assigned to that participant as *programmed* and *programmed but not tested*. No words assigned as *novel* for a participant were programmed on the AAC app for that participant, and consequently decoding of those words was never modeled by the app feature and interaction using those words never occurred.

Adapted Books for AAC App Exposure—Personalized adapted books were also created for each participant to serve as the intervention interaction context that provided exposure to models of decoding within the AAC app. Since the study was conducted remotely, the books were housed on digital slideshows, and contained screen captures of the AAC app with the decoding feature to allow participants to communicate using the app within a meaningful context. Three different adapted books were created for each participant based on favorite pop culture interests (e.g., TV shows, movies), identified through parent and self-report. These books each contained 32 pages (i.e., two pages for each for the 16 words in that participant's *programmed* and *programmed but not tested* word lists. The first page of the two-page sequence included a photo of a favorite character, a photo representing the word, and the text "What does [favorite character] see?" The second page of the sequence contained video screen captures of the AAC app modeling decoding of the target word as described earlier. See Figure 2 for an example of this two-page sequence for a target word.

Adapted Books for Probing Reading Performance—At each baseline session and throughout intervention, the individuals participated in probes to test their single word reading skills. For each participant, a second set of personalized adapted books were created based on their favorite pop culture references. Each book contained 32 pages – two pages dedicated to each word from the word lists assigned as *novel* (i.e., 8 words) and *programmed* (i.e., 8 words) for that participant; the 16 words appeared in a randomized order in each book. The two pages per word followed the same structure for each word. The first page showed a photo of the favorite character and a photo representing the target word with the text, "What does [character] see?" The second page provided a photo representation of the target word at the bottom of the page; above the photo, there was a grid display of six written words – the word being tested and five foils. The foils were other words from the study, with at least one containing the same initial letter sound as the target word. In order to accommodate remote data collection via Zoom, each adapted book for testing was housed on a digital slideshow. When the participant selected a written word from the grid display of six words via remote control of the investigator's screen, the outline around the word turned blue to signal selection to the researcher. Figure 2 shows an example of the two-page sequence for one word from the study.

Procedures

The second author conducted study sessions for Kora, and the first author conducted study sessions for Jay and Ben except for infrequent scheduling conflicts when the two authors stood in for one another. Participants had three sessions per week scheduled, though schedules were flexible to allow for cancellations as required due to scheduling conflicts. Kora and Jay completed all sessions from home while Ben completed sessions either at school or at home. For the most part, sessions were completed in a single day; however, sometimes sessions were split across days, especially during intervention when probes were often time consuming when participants sounded out all word choices per trial.

Audio Screening Procedures—For each session at baseline and intervention, after greetings, a brief audio screening was conducted to ensure that the participants' computer volume was sufficient for discriminating between different letter sounds. Participants selected a button from the screen that produced audio output of a word. Above the button were two photos representing minimal pairs (e.g., “hat” and “hit”). Participants selected the photo of the word they heard. This screening was completed for three minimal pairs. If the participants made an incorrect selection, the volume was adjusted, and the screening began again. Investigators made pseudorandom selections of the three minimal pairs for the screening each session from a larger bank of minimal pairs.

Baseline—Baseline sessions consisted only of a probe to measure the dependent variable. In order to test decoding skills, the investigators psuedo-randomly selected the slide show for one of the personalized adapted probe books. Using the slideshow, the investigator: (1) read the book page (see the first page in Figure 2 for an example); (2) named the target word; (3) used the target word in a sentence; (4) alerted the participant that it was their turn to read the word; (5) navigated to the word selection page that included a grid with six written words (see the second page in Figure 2 for an example); (6) instructed the participant to read all the words and then to select the word that matched the photo of the target word on the bottom of the selection page; and (7) waited at least 30 s, in addition to waiting through all on-task behavior (e.g., attempting to sound out the words), for a word selection. The investigator refrained from saying the target word once on the selection response page (i.e., step 5 above) in order to ensure that the participant phonologically recoded the word. The selection response pages contained word options as written text to avoid inadvertently testing memory of photo representations of concepts. The investigator provided no instruction on reading the words and provided no differential feedback on the participants’ responses. These same procedures were repeated through all 16 words assigned to each participant – the eight *novel* and eight *programmed* words from their assigned word lists. Throughout the probe, the investigator provided encouragement for participation generally (e.g., “Great job working hard!”) but did not provide specific feedback on responses. Finally, because probes were a demanding task, the participant was offered the option to sing a song or watch a video with the investigator to reward participation at the end of the probe.

Intervention—During the intervention phase, the investigator regularly conducted probes to test accuracy reading single words; the probes were completed at the start of the session and followed identical procedures to those that occurred in the baseline phase. The intervention phase also included interactions focused on adapted books that provided a motivating context for using the AAC app with the T2L feature that provided models of decoding. Specifically, the investigator pseudo-randomly selected one of the personalized adapted intervention book (on a slideshow). Then, for all 16 words (8 *programmed* and 8 *programmed but not tested*), the investigator completed the following sequence resulting in the app decoding each word twice: (1) navigated to the book page; (2) read the book page; (3) used a cloze phrase for the participant to complete with the target word; (4) navigated to the app page; (5) waited for the participant to communicate the word using the app via screen captures over Zoom, resulting in a model of decoding the word; (6) prompted use of the AAC app if the participant did not make a selection; (7) remained silent while the decoding model was presented by the app with phonological and orthographic output; (8)

expanded on the participant's communication by saying a related phrase including the target word, (9) modeled AAC use, completing the phrase by selecting target word to activate the screen capture of the AAC app, resulting in a decoding model of the target word; and (10) remained silent during the decoding model (phonological and orthographic output). During all AAC selections, the investigator remained silent while the app automatically provided a model of decoding (i.e., the written word appeared dynamically on the screen and enlarged upon selection of the target picture symbol, the individual letters were illuminated in sequence paired with voice output of their sounds, and the entire word was illuminated paired with speech output of the full word). The intervention consisted only of the interactions with the adapted books using the AAC app with the T2L feature that provided decoding models; the investigator did not provide any additional instruction or feedback.

Procedural Fidelity—Two undergraduate students in Communication Sciences and Disorders, blind to the goals of the study, were trained to evaluate the fidelity with which the investigators followed the study procedures across phases, both in terms of testing (probe procedures) and intervention using the AAC app with models of decoding. The student evaluating procedural fidelity in the probes was blind to the phase in which the probes occurred. Both students were trained using video recordings from study sessions to score the researchers' fidelity to the procedural checklist. Following training, the students scored a randomly selected sample of 23% of probes across participants and phases (i.e., baseline and intervention), and 23% of intervention sessions with the app modeling decoding across participants. This percentage surpassed the recommended 20% minimum to meet single subject research standards (Kratochwill et al., 2010). The selected samples did not include those videos with which the students were trained. For probes sessions, mean procedural fidelity was 95% (range 82%−99%) for Kora, 91% (range 82%−99%) for Jay, and 97% for Ben (range 95%−100%). For the intervention sessions with the app, mean procedural fidelity was 98% (range 92%−100%) for Kora, 99% (range 98%−100%) for Jay, and 98% (range 97%−99%) for Ben.

Measures and Data Analysis

Reading performance on 16 cvc words was the dependent variable in the study (i.e., accuracy with which the participants selected the target written word from a field of six written words upon presentation of a photo of the written word). The 16 words used to measure reading performance included 8 *novel* words (i.e., words not appearing at any point except during testing in order to ensure decoding skills had to be used to read the words) and 8 *programmed* words (i.e., words that were programmed on the AAC app with the decoding feature that the participant might read through decoding or possibly through word recognition). All data collection occurred live online during probes. For each word tested, participants' performance was scored as either correct (1) or incorrect (0), allowing for a total possible score of 16 for each probe. Correct responses were those where the participant selected the written word that matched the target photo provided. Incorrect responses included selection of a written word that did not match the target photo or no response from the participant after at least 30 s of off task behavior. The participants' first response was scored even if later self-corrected.

Data were line graphed following guidelines for reporting single-subject research (Kratochwill et al., 2013). Then, graphed data were visually analyzed for changes in trend, level, slope, and variability across phases. Immediacy of intervention effect was also visually analyzed; however, an immediate effect was not expected due to the complexity of learning to decode single words as a new skill. Further, data were analyzed using an effect size estimation, Nonoverlap of All Pairs (NAP) due to its power, precision, and strong relationship to visual analysis (Parker & Vannest, 2009). NAP was calculated by comparing baseline and intervention reading performance. NAP scores at or above 0.93 were suggestive of a strong effect, NAP scores between 0.66 and 0.92 suggested a moderate effect, and NAP scores below 0.66 suggested a weak effect (Parker & Vannest, 2009). Additionally, data were bar graphed using columns for each session to illustrate separately the participants' performance across the *novel* and *programmed* words that were included within the probes.

Interrater Reliability of the Dependent Variable—To ensure the data were reliable, an undergraduate student in Communication Sciences and Disorders was trained to score the probes from video recordings of the sessions. The student was blind to the goals of the study and to the phase of the study for each probe reviewed. After training, the student coded a randomly selected sample of 23% of baseline and intervention probes for each participant. The selected sample did not include those videos with which the student was trained. The data extracted by the student for each probe were compared to those extracted by the interventionists to determine point-by-point agreement. Interrater reliability was determined by calculating the total number of responses in agreement divided by the total number of words (i.e., 16) for each participant for each probe. That number was then multiplied by 100 to yield a percentage. Interrater reliability was 96% (range: 94%−100%) for Kora, 98% (range: 94%−100%) for Jay, and 92% (range: 81%−100%) for Ben.

Social Validity—At the end of the study, all participants completed a short interview to assess the social validity of the intervention. The interview was structured using a slideshow that provided visual choices of a green happy face to represent "yes", a yellow straight face to represent "I don't know", and a red sad face to represent "no". Interview questions were spoken aloud by the interventionists who then waited for the participants to respond through selection on the slideshow. The slideshow started with practice questions such as "Do you like when you get to eat your favorite snack?" to ensure the participant understood the task and could make accurate selections. Then the slideshow contained the following questions to assess social validity: (a) "Did you like spending time on the computer with [first author's name] and [second author's name]?" (with a screenshot of the two authors on a Zoom screen above the response choices), (b) "Did you like sounding out words with the computer?" (with a screenshot of the AAC app with the T2L decoding feature above the response choices), (c) "Did you get better at reading after sounding out words with the computer?", and (d) "Are you proud of your reading after sounding out words with the computer?". Though they weren't formally interviewed, the researchers also received unprompted informal feedback from each participant about the intervention throughout the course of conversations at the end of the study.

Results

Single Word Reading Performance

Participants' reading performance at baseline and intervention, as measured by their reading of 16 *novel* (n=8) and *programmed* (n=8) words, is graphed in Figure 3. Kora demonstrated consistently low performance in baseline with a mean of only 2.4 words correct out of 16 (*M*=15%), as would be expected by chance when selecting randomly from an array of 6. Her performance increased during the intervention phase following a delay, as hypothesized. Her performance in intervention, though higher than baseline overall, demonstrated variability from session to session (*M*=28% across the entire intervention phase). By the end of intervention (the last two probes), she read a mean of 8.5 words correctly in the probes, an average of 53% accuracy, representing a +38% increase from baseline to the end of intervention. Jay also demonstrated a consistently low level of baseline performance with a mean of 2.3 words read correctly (*M*=14% accuracy, chance levels of performance); he too showed an increase in accuracy during intervention after an initial, expected delay (*M*=30% across the entire intervention phase). His performance at the end of intervention was an average of 50% across the last two probes (mean of 8 out of 16 words correct), indicating a +36% increase from baseline to the end of intervention. Ben demonstrated some variability throughout baseline, although he showed relatively low reading performance overall (*M*=26%, mean of 4.1 words read correctly out of 16). Unlike the other participants, Ben showed a small but immediate increase in performance level at the beginning of intervention, followed by a continued increase and then levelling of performance (*M*=59% across the entire intervention phase). His performance across the last two intervention sessions was 69% accuracy on average (i.e., a mean of 11 out of 16 words read correctly), reflecting a +43% increase from baseline to the end of intervention. The NAP effect size estimations when comparing intervention to baseline was 0.83 for Kora, 0.84 for Jay, and 1.00 for Ben. These estimations represent a moderate effect of the AAC app with the T2L decoding feature for Kora and Jay, and a strong effect for Ben.

Although all of the participants demonstrated significant gains in their accuracy decoding, none of the participants achieved competence decoding novel words (i.e., >80% accuracy) within the relatively limited amount of intervention provided. Each intervention session with the AAC app with the T2L decoding feature lasted approximately 15 minutes. In total, participants spent an average of less than 4 hours across all intervention sessions (2.25h for Ben, 2.5h for Jay, and 7h for Kora who required more time with the app than the other participants to demonstrate consistent increases in decoding performance). As hypothesized, two of the participants did not demonstrate an intervention effect immediately with Kora requiring a total of 2.5 hours of instruction before demonstrating gains and Jay 1.25 hours; in contrast, Ben showed some gains in decoding immediately with an intervention effect established after the first two sessions (i.e., only half an hour) of intervention. Across all intervention sessions, the participants received an average of 501 models of words being decoded by the app while they communicated with it (288 models for Ben, 320 for Jay, and 896 for Kora). As noted earlier, each of the models took only approximately 11.25 seconds, for an average of only 93 minutes of the app modeling decoding to realize the effects observed (range 54–168 min).

Performance with *Novel* and *Programmed* Words

Figure 4 shows a breakdown of participants' reading performance each session across the 8 *novel* words (i.e., words that were never modeled by the T2L decoding feature during intervention interactions with the investigator) and the 8 *programmed* words (i.e., words that were modeled by the decoding feature in the AAC app during each intervention session). Since the participants were never exposed to the *novel* words at any time during intervention, any increases in performance reading these words had to result from the generalization of decoding skills to these new words. Since the *programmed* words were modeled by the T2L decoding feature in the AAC app during each intervention, it is impossible to know whether participants learned to decode or recognize those words. It is likely that the participants applied decoding skills to reading these words, given this was the reading process modeled by the AAC app used. However, it is also possible that the participants simply recognized the words from the models in the AAC app. Therefore, we also analyzed the participants' performance separately for the *novel* and *programmed* words.

Participants demonstrated similar increases across their reading of *novel* and *programmed* words as illustrated by the graphs in Figure 4. For *novel* words, participants' mean performance in baseline and in the last two intervention sessions were: 15% (baseline) and 50% (end of intervention) for Kora, 12.5% (baseline) and 44% (end of intervention) for Jay, and 27.5% (baseline) to 69% (end of intervention) for Ben. For *programmed* words, participants' mean performance in baseline and in the last two intervention sessions were: 15% (baseline) and 56% (end of intervention) for Kora, 16% (baseline) and 56% (end of intervention) for Jay, and 24% (baseline) to 69% (end of intervention) for Ben. NAP scores specific to *novel* and *programmed* words respectively were as follows: Kora = 0.81 and 0.68, Jay = 0.79 and 0.74, Ben = 0.96 and 0.87.

Social Validity

Overall, results of the social validity questions were positive. All three participants responded "Yes" to feeling they had improved their reading, that they were proud of that improvement, and that they enjoyed spending time on the computer with the first and second authors during intervention. Two of three participants responded "Yes" that they had enjoyed sounding out words on the computer with the third responding "I don't care".

Informally, parents also shared several anecdotes during interactions with the researchers about scheduling or the end of intervention, and while making small talk. Specifically, Jay's mom stated that she was never sure how much progress he was making in school, but with this intervention she could tell his literacy skills were increasing. Kora's mom stated that her teachers had tried to teach her decoding in the past, but this was the first time that Kora "really gets it." Ben's mom shared that she noticed his confidence around reading had increased, and that he was attempting to read more words in daily life. Parents of all three participants also expressed an interest in continued use of the app with the T2L decoding feature and in continuing to support decoding using materials from the study. Thus, after all study-related activities were completed, all participants received access to study materials to support their continued literacy learning.

Discussion

Full participation in adolescent and adult life is in many ways predicated on the use of functional literacy skills – from texting friends to navigating an unfamiliar location to ordering from a menu (Holyfield & Caron, 2019). The lack of functional literacy skills held by most adolescents and adults with Down syndrome and limited speech (McNaughton et al., 2021), therefore, restricts their full participation in the everyday contexts those stages of life encompass. Recent research and development have significantly advanced the efficacy of AAC technology design in improving outcomes for individuals with intellectual and developmental disabilities and limited speech, including in relation to single-word reading (Light, Wilkinson, et al., 2019).

Effect of the T2L Decoding Feature

Prior research has demonstrated the benefits of a transition to literacy (T2L) feature specifically designed to support *sight word* reading (e.g., Holyfield et al., 2020). The current study represents the first empirical evidence suggesting that a T2L AAC technology feature can be designed to support the development of *decoding* skills. Though results from this study are preliminary, all three participants showed an increase in their decoding skills as evidenced by increases in their accuracy reading, not only words for which decoding was modeled on the AAC technology during intervention interactions, but also increases in their accuracy decoding novel words that were never modeled during intervention. Importantly, all three participants also reported feeling that their reading had improved, and that they were proud of that improvement. It is important to note that the T2L decoding feature was integrated into an AAC app and provided the participants with increased exposure to models of decoding, but it did not provide explicit instruction in decoding. Further, at no time during the intervention did the participants receive any specific instruction in decoding from the investigators or any feedback on their responses during the probes. Thus, increases in decoding accuracy observed resulted simply from repeated exposure to models of decoding of a variety of cvc words provided by the T2L feature.

There are a number of factors that may have contributed to the positive impact of the T2L decoding feature. The development of the app was driven by current research and theory on literacy learning as well as on the processes underlying human-computer interaction (e.g., visual, auditory, and cognitive processes). Specifically, the T2L feature was developed to support the processes required for decoding including: orthographic processing (e.g., recognition of letters in the context of words); phonological processing (e.g., knowledge of letter sound correspondences and blending of letter sounds to support phonological recoding of written text); and meaning processing (i.e., association of the written word with its meaning). The T2L feature applied scientific knowledge of basic human-computer processes to support the processes underlying decoding. Specifically, the feature utilized smooth animation of the target word to drive the participants' visual attention to the written text, thus supporting orthographic processing; the research on visual cognitive processing demonstrates that motion is a powerful attractor of visual attention (Jagaroo & Wilkinson, 2008). The T2L decoding feature then used luminance to attract visual attention to the individual letters in each word in sequence (Turatto & Galfano, 2000), thus supporting visual attention to the letters in sequence; like motion, the visual cognitive processing research demonstrates that luminance is a powerful attractor of visual attention; unlike motion, luminance draws attention to individual letters while preserving their position in the context of the letter sequences in the full word (Jagaroo & Wilkinson, 2008). The decoding feature then paired each illuminated letter with its sound, demonstrating the application of letter sound knowledge. Finally, the feature modeled blending of the individual sounds to derive the target spoken word, thus modeling phonological recoding of the written text. Finally, the T2L feature resulted from selection of higher transparency representations in the AAC app, ensuring understanding of the meaning of the written words. Thus, the T2L decoding feature was designed to maximize visual attention to the orthography of the target words, to support phonological recoding of the written text letter by letter, and to ensure understanding of the meaning of the target words through their explicit links to known or transparent AAC picture symbols such as color photos. Finally, the intervention occurred within a motivating context using adapted books with favorite characters, potentially increasing motivation.

Efficiency of the T2L Decoding Feature

Intervention was designed to maximize exposure to models of decoding across a range of different cvc words to increase efficiency. Specifically, during the intervention phase, participants were exposed to models of decoding a total of 32 times per session (i.e., 16 different words, each modeled twice per session), for a total of approximately 896 decoding models for Kora, 320 for Jay, and 288 for Ben during the entire study. As noted earlier, each model of decoding a cvc word took only 11.25 seconds, for an average of only 93 minutes of the app modeling decoding (54 min for Ben, 60 for Jay, and 168 min for Kora) to realize the gains in decoding observed (i.e., increases of 36% to 43% accuracy by the end of intervention).

The intervention sessions included interactions in the context of the adapted book; the decoding models were embedded in these conversational interactions. In general terms, the intervention interactions lasted approximately 15 minutes per session in total (including 6 minutes of decoding models through the T2L feature). Overall the participants only spent a short amount of time in intervention sessions, approximately 7 hours total for Kora, 2.5 hours for Jay, and 2.25 for Ben. Thus, participants in this study demonstrated increases – albeit limited increases – in reading performance indicative of increased decoding skills in a limited amount of time. This offers initial evidence to suggest that it may serve as useful supplement and complement to explicit literacy instruction for individuals with complex communication needs.

As hypothesized, the impact of the T2L decoding feature was not immediate for two of the three participants (Kora and Jay); as expected, these two participants required exposure to numerous models of decoding across several intervention sessions before they began to show improved performance during the probes. In contrast, Ben demonstrated immediate, albeit relatively modest, gains in decoding after introduction of the AAC app with the T2L feature that modeled decoding. Initial gains in decoding (i.e., accuracy in decoding novel words greater than the highest baseline point in at least two consecutive probes) were observed after 10 intervention sessions (320 decoding models) for Kora, 5 sessions (160 models) for Jay, and 2 sessions (64 models) for Ben. Participants spent an average of 1.4 hours interacting with the app during intervention before demonstrating an intervention effect for reading novel words. This represents a longer amount of time interacting with the app than was required by all participants with Down syndrome in a previous study evaluating the AAC app feature designed to promote single-word recognition (Holyfield et al., 2020). The three participants with Down syndrome in that study required no more than 45 minutes interacting with the single-word recognition app. However, decoding is a more complex skill to learn (Light & McNaughton, 2013; Yorke et al., 2021) and thus it is not surprising that more time interacting with the decoding AAC app was required.

It is important to note that, although the participants all demonstrated significant gains in their decoding skills with simple exposure to the T2L feature that modeled decoding, none of the participants attained competence (>80% accuracy) in decoding in the limited time frame of this study. Based on the trends observed in the intervention phase, it seems reasonable to suggest that their decoding skills would have continued to improve with increased exposure. However, this hypothesis must be tested in future research given the limited time frame of this study.

As noted earlier, the decoding feature was conceptualized not as a replacement for explicit instruction in decoding, but rather as a complement to this instruction, providing additional exposure to models of decoding throughout the day as appropriate. This research study only considered the effects of the decoding feature in isolation to ensure experimental control, but it seems reasonable to suggest that the effects of the decoding feature might be amplified if the app were used by participants for additional exposure to models of decoding in conjunction with explicit instruction. In order to ensure experimental control, the participants in this study did not receive any feedback on the accuracy of their responses during the probes, allowing them to repeat errors without correction. During typical instruction, participants would receive feedback on the accuracy of their responses, thus limiting the entrenchment of error patterns and no doubt increasing the rate of learning. Future research is required to investigate this hypothesis.

Performance with Novel and Programmed Words

We had hypothesized that the participants would show an earlier increase in their accuracy reading the words programmed on the app than those that were novel; however, this was not the case. Two participants did demonstrate slightly higher accuracy levels reading the *programmed* words (modeled by the app) by the end of the intervention as compared to the *novel* words (e.g., 56% accuracy compared to 50% for Kora and 56% compared to 44% for Jay). The third participant (Ben) performed with similar levels of accuracy across both sets by the final two intervention sessions (i.e., 69% accuracy for both programmed and novel words). The programmed words might have offered an advantage as the participants could either decode these words or recognize them by sight to read them correctly. However, the results suggest that the participants applied decoding skills to read both types of words, leading to similar levels of performance across the *programmed* and *novel* words. This possibility is supported by anecdotal observations of the probes in which the participants attempted to say each of the letter sounds and then blend the sounds together (as demonstrated in the decoding models in the AAC app). In fact, estimated effect sizes of intervention for each participant were slightly higher for *novel* words than *programmed* words. Given the closeness of effect sizes across word types, however, the slightly higher NAP scores for *novel* words may not reflect an actual difference in intervention effect across the word types. Further research is needed to understand why the participants did not demonstrate any advantage when reading the words familiar to them through interacting with the app.

Clinical Implications

Clinicians understand the power of literacy in supporting the use of AAC technologies by individuals with complex communication needs; word recognition allows for the meaningful use of text representations, and functional literacy allows for the generation of any message using only the alphabet (Light & McNaughton, 2013). The current study contributes to recent research indicating that the reverse can also be true (Light, McNaughton, et al., 2019). That is, use of theoretically-sound, research-based AAC technology can be supportive of literacy skill development. Thus, the two can have a positive reciprocal effect on one another – with literacy growth expanding communicative opportunities and increased communication, in turn, promoting opportunities for literacy development.

More research is needed before strong clinical recommendations can be made, but this study offers clinicians preliminary evidence that adolescents and adults with Down syndrome who had previously developed little to no decoding skills can make gains toward that end, simply through interacting within motivating contexts using an AAC app with the newly developed T2L decoding feature enabled to provide models of decoding upon selection of target picture symbols. Although this study shows the potential value of this new decoding feature in promoting literacy development, it is important to note that the decoding models decrease communication rate and may be disruptive or confusing when used with unfamiliar partners during interactions. Therefore, clinicians should carefully consider contexts in which the feature could be activated to support literacy learning without disrupting communication, such as those in which communication rate is not demanding and communication partners are supportive. For instance, interacting with family at home may be a good time to enable the feature. Alternatively, clinicians should also consider the programming of motivating material such as that used in the current study to offer opportunities for individuals who rely on AAC to independently explore use of the decoding feature to increase exposure to decoding models without sacrificing communication efficiency. One of the clear advantages of the decoding feature is that it is easy to use by individuals with developmental disabilities and their communication partners; no special training is required. This ease of use may be especially important for adolescents and adults with Down syndrome who may have aged out of educational programs that provide regular literacy instruction and who may not have access to instructional experts.

The T2L decoding feature investigated in this study complements the T2L sight word feature that is already available in a range of VSD and grid based apps. In interactions when the use of the new decoding feature may not be appropriate, based on previous research (Holyfield et al., 2020), clinicians could instead consider enabling the T2L feature designed to support single-word recognition (Light et al., 2014). When deciding whether to implement the decoding feature or the sight word recognition feature, clinicians should not only consider the nature of the interaction, but also the nature of individual words and whether these words lend themselves better to recognition learning (e.g., an irregular word like “light” or a word that may initially be difficult for learners to decode like “imagine”) or whether the words are regular and lend themselves to decoding (e.g., words like “bed” or “stop”). Clinicians could then enable the different literacy features for different words on the AAC device.

Importantly, this AAC technology was not designed to replace instruction in decoding, but rather to supplement instruction by providing additional exposure to models of decoding. Therefore, clinicians must remember the compelling evidence that supports implementation of adapted instruction to build literacy with individuals with intellectual and developmental disabilities and limited speech, including those with Down syndrome (Yorke et al., 2021). As such, it is important that clinicians do not use this feature to replace literacy instruction; rather it should be used in conjunction with explicit literacy instruction.

Limitations and Directions for Future Research

The current study was limited in important ways that restrict the conclusions that can be drawn from it. Most notably, only three individuals participated in the study. To develop stronger clinical guidance relative to the use of this new AAC feature for decoding, future research should investigate whether the positive effects observed in this study are observed with other individuals who rely on AAC. Such research could expand the ages and diagnoses of participants to explore the app feature’s efficacy across the lifespan and across different disabilities.

The current study was completed in a limited time span; intervention was terminated before the participants acquired competence in decoding (i.e., >80% accuracy decoding novel words). Also due to time limitations associated with scheduling constraints, maintenance probes were not collected in the study. Future research should extend long enough to investigate the development of competence in decoding and to determine long term maintenance of these skills.

While decoding is a skill integral to functional literacy and to typing (i.e., encoding) words to communicate, the current study did not include measures related to the impact of increases in decoding skills on generative expression through AAC. Future research should include generalization measures focused on encoding as, for people who use AAC, this generalization of decoding skills to written communication is a major potential benefit of growing those skills.

This study included measures of social validity, but those measures had limitations. There was an opportunity for bias in the social validity responses received since the researcher who provided the intervention posed the questions. Participants could have felt social pressure to provide a positive response. Future research should include more robust measures of social validity that are designed to reduce any biases.

Further, this study was limited in scope in that it applied the app to a relatively small corpus of words, integrated the app into a structured interaction context around highly motivating content, and measured decoding through a task developed for research. To comprehensively understand the effects of the new T2L decoding feature on the communication of individuals with intellectual and developmental disabilities, future research must investigate use within naturally occurring contexts. Not only should the T2L feature be integrated into daily life and regularly occurring communication contexts to establish ecological validity of the intervention, but any effects of the T2L decoding feature on everyday communication should also be evaluated. Since the app was conceptualized as an augmentation, not a replacement, for literacy instruction, future research should also investigate the effects of the decoding feature when used in conjunction with instruction.

Because of the COVID pandemic, this research was implemented remotely. Doing so, had a number of important benefits: it opened the research to an increased number of participants over a larger geographic region; it provided relatively independent access to meaningful and motivating literacy intervention, including for an adult who had aged out of formal literacy instruction; it was efficient and convenient for both the participants and the researchers since travel was not required and scheduling could be more flexible; and it allowed participants to learn in a comfortable and familiar setting. Of course, the adaptation to a remote context also resulted in some limitations. Such an adaptation was necessary and allowed for intervention research during a time in which in-person intervention research was impossible. Still, use of AAC apps and their features overwhelmingly occur in person. Therefore, it is important that in-person use of this AAC app feature is explored in future research.

Conclusion

Research shows that adolescents and adults with Down syndrome and other intellectual and developmental disabilities who have limited speech can build foundational literacy skills when given the opportunity through effective instruction (Yorke et al., 2021). Even when access to effective instruction is restricted, research shows that adolescents and adults with Down syndrome can increase single-word reading through access to AAC technologies effectively designed to support sight word recognition skills (Holyfield et al., 2020). With the current preliminary study, research now shows that AAC technologies can also be designed to increase decoding – a skill central to functional literacy. Much more research is needed to evaluate the efficacy of this newly developed T2L decoding feature (Light, McNaughton, & Jakobs, 2019). Particularly urgent is research exploring the efficacy of the feature when used in real-world contexts and the effects of any decoding skills on literacy-based communication using AAC and other technology platforms such as e-mail. However, based on the promise of this initial study, incorporating this feature into AAC technologies has the potential to unlock opportunities for adolescents and adults with Down syndrome not only to develop decoding skills, but to participate more fully in social, vocational, educational, and community-based life arenas through literacy.

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Data Availability Statement

The data generated in this study are available in the Open ICPSR repository, /openicpsr/137141.

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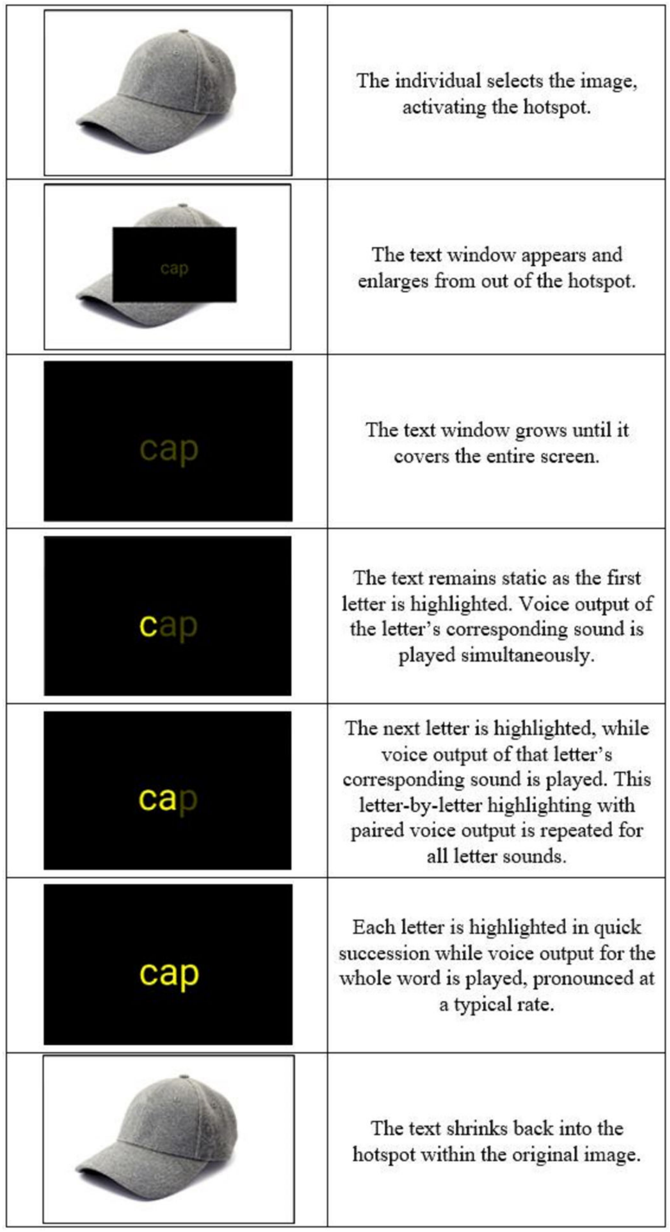

Figure 1.

Still images of the AAC feature to support decoding at key points in the feature process with corresponding descriptions.

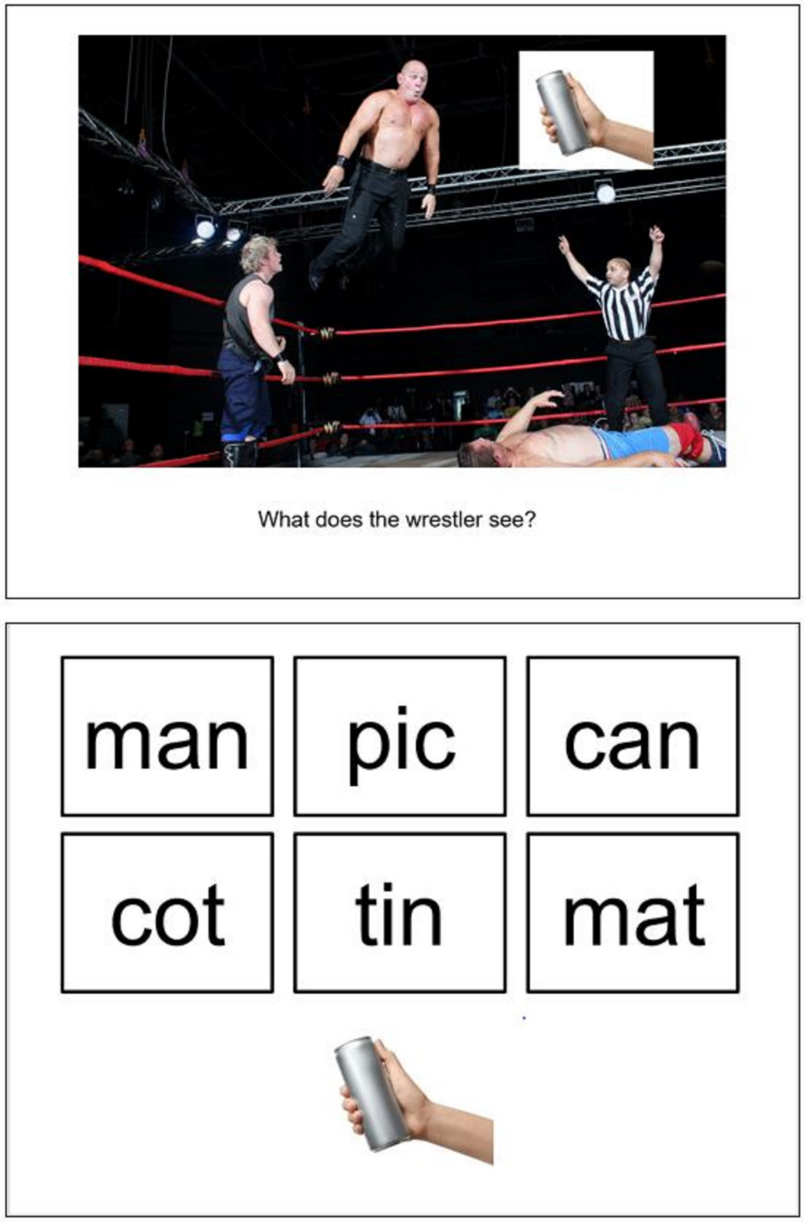

Figure 2.

Example of adapted book pages used for testing single word reading during the probes at baseline and intervention.

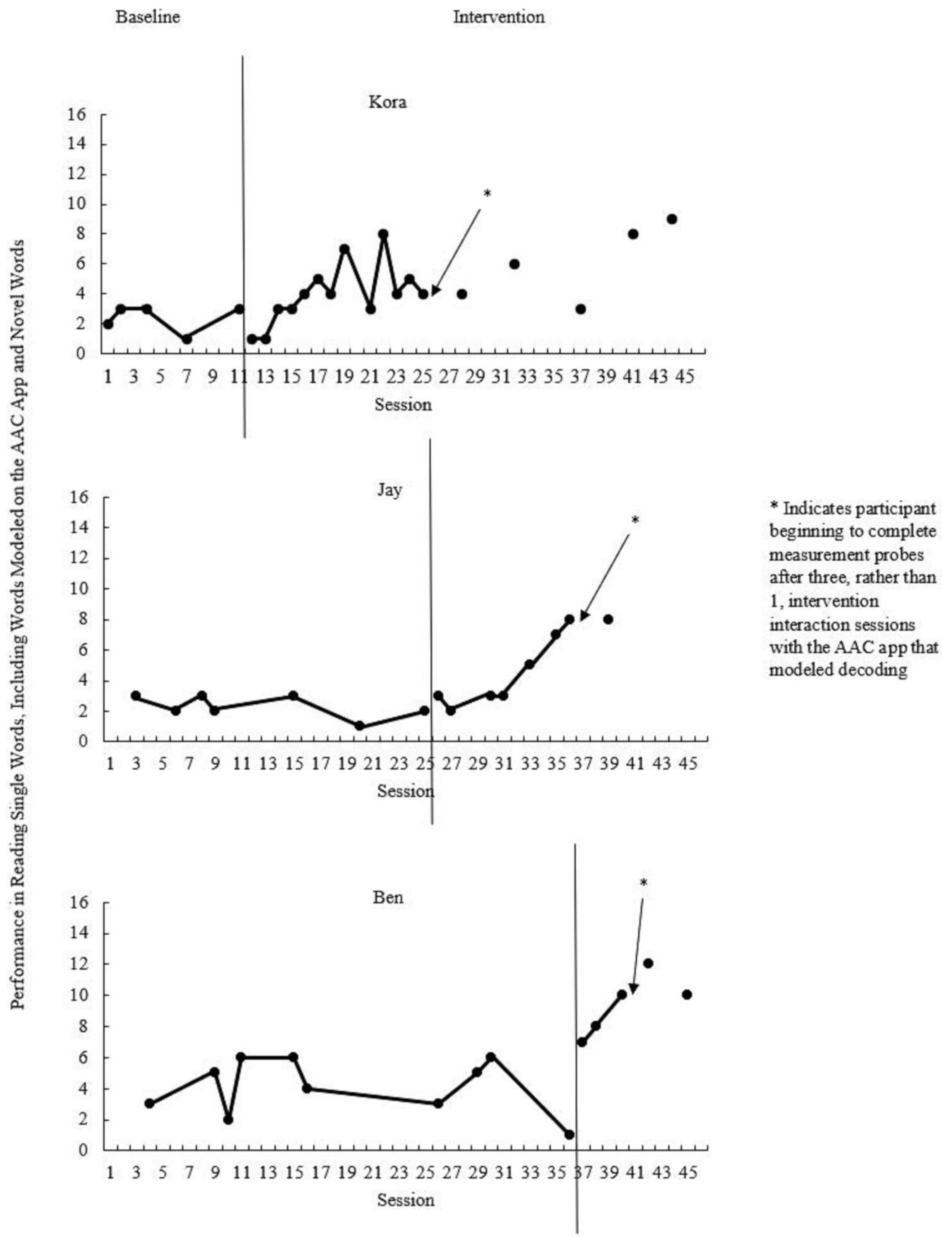

Figure 3.

Single words read accurately by participants, as indicated by their selection of the correct word out of a field of six, including performance across both words programmed on the AAC app to model decoding (8) and novel words never appearing on the AAC app (8). AAC = augmentative and alternative communication.

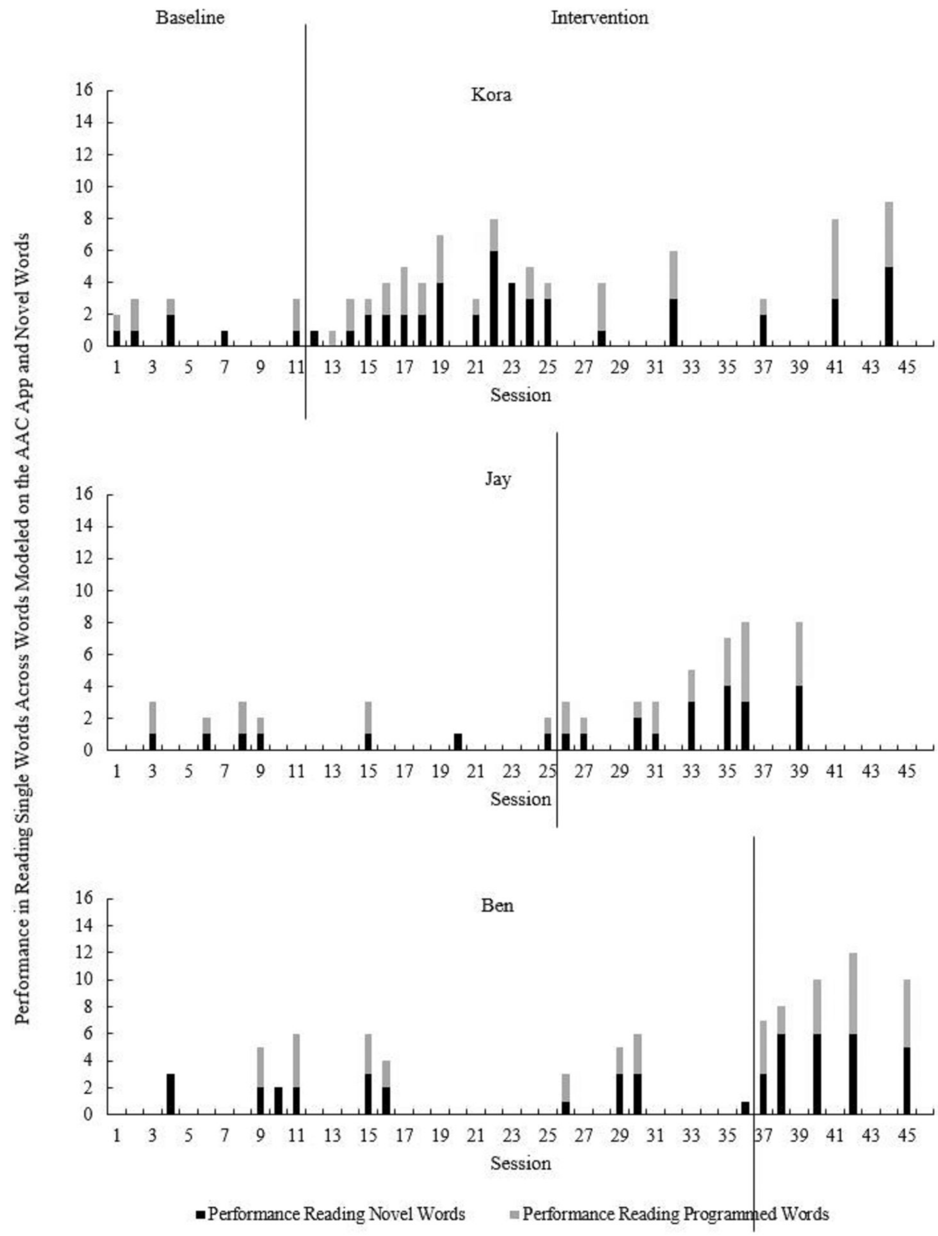

Figure 4.
Participant single word reading performance demarcated across programmed and novel words. AAC = augmentative and alternative communication.

Table 1

Descriptive information about participants

	Kora	Jay	Ben
Age	27 years old	11 years old	15 years old
Gender	Female	Male	Male
Race	White	Black	White
Developmental disability	Down syndrome	Down syndrome	Down syndrome
[a]Educational or vocational setting	Volunteer at nursing facility and retail store	Student in special education middle-school classroom	Student in special education middle-school classroom
[a]Hearing and Vision	Within normal limits	Within normal limits	Within normal limits
[a]Primary communication modes	Speech, signs, gestures, AAC app	Speech, gestures, signs	Speech, signs, gestures
[a]Description of natural speech	Infrequently understood by unfamiliar listeners	Infrequently understood by unfamiliar listeners	Infrequently understood by unfamiliar listeners
[b]Letter sound correspondence knowledge	3/26	19/26	23/26

[a]Information gathered through family report and observation.

[b]Information gathered through study pre-screening.