TalkingBoogie: Collaborative Mobile AAC System for Non-verbal Children with Developmental Disabilities and Their Caregivers

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ABSTRACT
Augmentative and alternative communication (AAC) technologies are widely used to help non-verbal children enable communication. For AAC-aided communication to be successful, caregivers should support children with consistent intervention strategies in various settings. As such, caregivers need to continuously observe and discuss children's AAC usage to create a shared understanding of these strategies. However, caregivers often find it challenging to effectively collaborate with one another due to a lack of family involvement and the unstructured process of collaboration. To address these issues, we present TalkingBoogie, which consists of two mobile apps: TalkingBoogie-AAC for caregiver-child communication, and TalkingBoogie-coach supporting caregiver collaboration. Working together, these applications provide contextualized layouts for symbol arrangement, scaffold the process of sharing and discussing observations, and induce caregivers' balanced participation. A two-week deployment study with four groups (N=11) found that TalkingBoogie helped increase mutual understanding of strategies and encourage balanced participation between caregivers with reduced cognitive loads.

Author Keywords
AAC; developmental disability; assistive technology; caregiver collaboration; accessibility

CCS Concepts
•Human-centered computing → Accessibility systems and tools; Computer supported cooperative work; •Social and professional topics → *People with disabilities;*

INTRODUCTION
A lot of children with developmental disabilities, such as autism and cerebral palsy, have difficulties producing functional speech [6]. For example, approximately 14-20% of children with autism are estimated to produce little or no functional speech [27]. To help these heterogeneous groups effectively communicate with adults and their peers, augmentative and alternative communication (AAC) devices have been widely used, where non-verbal children can click symbols displayed on the device to generate synthetic speech through text-to-speech (TTS) technology [7].

To facilitate effective communication of the child using AAC, caregivers such as parents, teachers, and speech-language pathologists continuously assist the children [22]. For instance, caregivers need to personalize device settings such as sorting the frequently used symbols to enhance the communication rate. For such AAC interventions to be successful, it is indispensable for caregivers to accurately assess the communication abilities of a child [11] and then support the child with consistent strategies throughout a variety of settings [7]. In this process, a collaboration between caregivers around the child is considered essential [3]. By sharing their observations with each other, caregivers can prevent fragmented observations and get a more accurate understanding on the development of each child [33].

Nevertheless, caregivers often find it challenging to effectively share observations and achieve a consensus [1, 30, 36], and still, to the best of our knowledge, there is no AAC device that provides support for caregivers to effectively collaborate with each other. While several existing studies have explored collaboration on AAC, they place agency or professional therapists at the center of collaboration, deeming the role of family members as mere informants [11]. Relying on an agency or experts, however, is limited in that it is often costly, episodic, and less accessible. Instead, supporting collaboration between closer and long-lasting caregivers, such as teachers or parents, will allow a more sustainable approach to address the limited transfer of skills from therapy to daily life [12, 35]. As such, we aim to design an AAC application that incorporates the assistance of this collaboration between teachers and parents.

To better understand the challenges in cooperation among parents and teachers, we conducted a semi-structured interview session with three parents of non-verbal children using AAC and three special education teachers. From the interview ses-

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sions, we identified two major difficulties: impediments to balanced participation between caregivers, and inefficiencies arising from excessive manual work of sharing observation on a child with unstructured channel of contact.

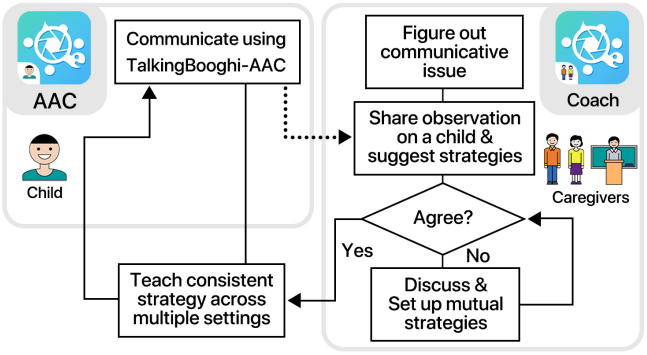

Figure 1. The overall process of TalkingBoogie collaboration

Based on the design implications, we present TalkingBoogie[1], a collaborative AAC system deployed on mobile devices to ensure consistent and up-to-date collaboration. Our system consists of two mobile applications: TalkingBoogie-AAC and TalkingBoogie-Coach. TalkingBoogie-AAC contains three layouts that are easy to be setup, also by unprofessional caregivers, and also help convey the context of conversation. TalkingBoogie-Coach scaffolds the process of sharing/discussing the observations, along with the automated support for tracking and analyzing the data on a child's AAC use.

In order to evaluate TalkingBoogie, we ran a two-week deployment study with four groups, each of which included a child, a parent, and a special education teacher. From the evaluation, we could identify that TalkingBoogie helped increase the mutual understanding of intervention strategies. Also, TalkingBoogie encouraged the balanced participation between caregivers with reduced cognitive loads.

The contributions of the paper are as follows:

- In-depth interviews with caregivers of AAC users that revealed challenges for caregivers to effectively collaborate with each other and ultimately facilitate the successful communication of a child using AAC
- TalkingBoogie, a mobile AAC system that supports not only communication with the child but also collaboration between caregivers on intervention strategies, thereby extending the scope of research on AAC from child-device interaction to the environment surrounding the child
- Results from a two-week deployment study with real-world users showing the feasibility of a collaborative AAC system

RELATED WORK

Augmentative and Alternative Communication

AAC technologies enable children with needs of communication support to enhance their communication, language, and literacy outcomes [25]. Consisting of icons called 'symbol', which depicts a specific object or concept as an image, AAC allows children to express their ideas by clicking on symbols and composing sentences on its display.

Figure 2. Example of AAC deployed on electronic devices. Proloquo2go (left) by AssistiveWare and Sono Flex (right) by Tobii Technology

Although these applications have great significance in assisting those with difficulty in communicating verbally, their slow speed has often been highlighted as an issue. The rate of AAC is known to be below 10 words per minute [28], considerably less than that of verbal communication. Thus, seeking for methods to overcome the speed limitation has been the main research focus for AAC researchers. Previous studies have investigated novel methods of suggesting symbols based on user's previous usage and current context (prediction) [37, 38, 39], or retrieving a phrase/sentence with one or multiple sentences (encoding) [2, 20].

However, children with developmental disabilities are yet to fully develop their communicative competence, and often suffer from learning demands derived from their disabilities. Thus, rather than mere enhancement of the input rate, which may not be the best approach for such beginning communicators, HCI researchers have extended the scope of research by exploring methods to enhance a child's communicative willingness and participation on AAC devices; to be specific, they have focused on designing an interactive AAC system that appeals to children. Considering that the existing AAC systems do not appeal to children [23], Jeon et al. [18] integrated AAC into a robot to seek opportunities of child's enhanced participation. Black et al. [9] focused on the importance of personal narrative in communication and designed a mobile application that helps in constructing personal narratives with data gathered by scanning an object's barcode and recording a voice. Through the design progress, researchers have sought the feasibility of designing AAC systems that appeal to children.

In this contribution, we extend the focus of AAC design by considering not only a child's interaction, but also the environment surrounding children and their devices. To be specific, we view children's caregivers as crucial stakeholders of our design and included them within our system by supporting collaboration among caregivers.

Caregiver Collaboration for the Child Development

In observing and empowering child development, caregiver collaboration is highly emphasized to make precise observations and set up appropriate decisions [14, 34]. As information from informants across multiple settings offer various and consistent views on child development, many researchers have

[1] *Boogie* is a Korean word meaning for "turtle", an animal which is known for its slow movement. TalkingBoogie is named to reflect the aim of an AAC system to help children effectively communicate with others even if it might require a long time.

raised awareness on the importance of collaboration in child observation and assessment. Kientz et al. investigated the need of networking among diverse stakeholders in a child development tracking situation [19]. Seeking for the feasibility of family-centered observation, Song et al. designed a collaborative system for tracking a child's developmental phase in a family setting [33].

Caregiver collaboration is especially considered an essential approach in assisting the communication progress of a child with communication disorders [4, 10]. With richer information on child communication gathered from multiple caregivers, these can establish more precise decisions on setting up AAC intervention strategies. In addition, collaborative approach in AAC intervention is helpful in maintaining consistent intervention. A collaborative approach in AAC intervention is also helpful in maintaining consistent strategies that makes children feel less exhausted during the interventions [1].

Previous studies have explored collaboration and decision-making progress through meet-ups among caregivers including clinicians, speech-language pathologists, teachers, and parents [11, 32]. These studies have implemented collaboration among caregivers by (1) finding evidences through observing children in clinical and home settings, (2) examining and synthesizing these evidences, and (3) applying and evaluating the resulting strategies. However, these studies have mainly focused on collaborative decision-making progress in clinical or agency settings which generally takes place for only several hours per a month. Rooted in the ability of having consistency through mobile systems, in this study, we seek to design a collaborative AAC system where caregivers can consistently observe a child and discuss suitable strategies with each other remotely for enhancing a child's communicative competence.

PRELIMINARY STUDY

To better understand the caregivers' current challenges in the collaboration for enhancing the child's use of AAC, we conducted a series of interviews with parent and teacher groups of children with non-verbal developmental disabilities.

First, we contacted local special education schools to recruit caregivers of non-verbal children with developmental disabilities whose communication is dependent on AAC, and who were aged from 6 to 15 years (elementary~middle school age). We recruited three teachers (T1-T3) and three parents (P1-P3) of children who were attending the local special education schools. After the recruitment, we had a semi-structured interview with each caregiver. During the interview, we received various reports across the following topic areas:

- Reports over the current use of AAC of a child
- Self-reported role in collaboration among caregivers
- Factors that undermine successful collaboration for the child's use of AAC
- Each method of the caregiver for dealing with a child's communication issues

Each session lasted about 30 minutes, and the interview responses were open-coded, where the first and second author of the study iteratively clustered the issues in collaboration. The key issues in collaboration are summarized as follows.

Impediments to a balanced participation

When dealing with communicative issues of the child (e.g., conversation breakdown), teachers, who are trained on AAC intervention and comparatively short-term observer of a child, reported that they often make up and teach various strategies to enhance the child's AAC-aided communication and share observations with parents. Contrarily, parents responded that they often could not actively try out strategies on AAC to resolve the communication issues nor share them with teachers. Such lack of parental involvement often causes teachers to depend only on their own observations. This not only limits the teachers from broadening their knowledge about the child, but also burdens them with isolation: *"Sharing observations is usually done one-way from me to parents, and I need to get more information to drive better decisions on a child." (T1)* From the interviews, several challenges were identified that leave the parents less motivated to actively use AAC and share issues with another caregiver.

Difficulty of assisting a child to express ideas with AAC

Existing grid based AAC systems require the child to compose a sentence by arranging the symbols with little support from the system. As constructing sentences on their own is often a huge burden to beginner communicators, or those with severe disabilities [8], active support from caregivers is essential to help them successfully express their thoughts. However, caregivers, especially parents with no prior knowledge on AAC education, consider it challenging to teach children how to compose symbols in the AAC display. Such difficulty makes parents to rely on the efforts of teachers with little participation and even sometimes abandon AAC: *"Due to the lack of assistance on constructing sentences with symbols, I couldn't learn how to teach AAC and talk about the experience, often ending up abandoning AAC." (P1)*

Preference for nuanced information on resolving child's communication issues

It is important for caregivers to persist in dealing with the issues using AAC for the future communication of a child with other communication partners, rather than focusing on other *nuanced* means (e.g. facial expression, eye staring) that only parents can understand and interpret. However, when resolving the child's communication issues, parents often prefer to resolve them instantly with such nuanced information as to figure out the intention of their child, rather than actively trying out AAC strategies and teach the best one for child to enhance child's communicative competence for the similar situations in the future: *"When I identify a problem when my child uses AAC, I don't wait for child to express via AAC (because it takes too long time.) Rather, I see his eyes to notice gaze and try to notice his thought." (P2)*

Underestimating the significance of sharing observations of a child and discussing them

Although the continual observations and opinions of caregivers are highly valuable for the future communication of a child, parents often regard their own observations and opinions as trivial due to a lack of motivation and confidence in their role:

"I don't think communication issues I noticed were big enough to share compared to those shared by teacher." (P1) We also noticed this perception of parents in a discussion on the communicative issues of the child between caregivers. During the interview, T3 illustrated a difficulty resolving different opinions when there is a disagreement over a child's vision and the icon sizing for the child. Rather than actively discussing and drawing the best strategic decisions across settings, T3 noted that the parent soon followed her opinion due to the lack of willingness: *"I and the parent had a disagreement about the icon sizing which fits the child's vision before. I wanted her to actively resolve the issue, but she just followed my opinion . . . which was later found out to be too small."* (T3)

Inefficient Process of Collaboration

Manually tracking child development and sharing the observations is often a tedious process for caregivers. Not surprisingly, caregivers in the interview all pointed out the inefficient process as a major barrier against successful collaboration. It was found to not only burden the parents and the teachers, but to also cause misunderstandings between caregivers due to discrepancies in what and how they share information about the child's AAC usage. Responses from caregivers are summarized with the following issues below.

Manual and unstructured channels of contact

Caregivers deliver their observations manually through unstructured communication channels, such as mobile messenger and phone calls. In this process, teachers reported that parents often ask teachers about irrelevant or unimportant topics (e.g., the daily meal and every little behavior of a child). Consequently, discussion between caregivers often ends up as merely listing trivial events rather than drawing a conclusion on appropriate intervention strategies from meaningful observations. However, unstructured channels do not provide any guidance on what to focus on nor any feature to control the focus of attention, leaving teachers to suffer from the excessive workload: *"A lot of parents try to contact me every day to ask about a child's daily issues . . . burdensome for me to report every observation for parents through personal contact. It would be better if parents can also actively participate in observing child communication just like me." (T1)*

Difficulty of sharing the conversational contexts of a child

Caregivers in the interview complained that a contextual misunderstanding occurs when referencing a specific conversation between a child and caregiver and then explaining it to the counterpart. For example, P3 was talking about the 'Love' symbol with the teacher. Her child used the symbol for the meaning of both 'I want to do it' and 'I like it'. The teacher shared to a parent that the student clicked 'Love' and 'TV' symbols the whole day, which the parent interpreted as her child expressing a desire to watch a TV program. It took a while for the parent to find out that the child did not want to watch the program, but was just expressing that she liked the hero in TV program in school setting. This example illustrates the challenges of sharing context of conversation using AAC, and that caregivers also need a common way to to refer to a specific context: *"I and the child's parents sometimes misunderstand each other while sharing the child's specific event . . . I guess it would be good if we can share some 'shaped information' using AAC to avoid mutual misinterpretations." (T3) "When teachers hand out assignments of using AAC, I sometimes can't understand the exact context and intention which makes it difficult to assist my child with the assignment. I would readily initiate this it if I got some guidelines." (P2)*

Figure 3. Symbol boards that teachers organized and printed out. Due to the difficulty of teaching a child how to compose symbols in AAC devices and referencing their conversations, some caregivers created customized symbol boards and shared them with the other caregiver.

Even worse, leaving this difficulty unaddressed ultimately results in making children exhausted from communication. By keeping this inconsistency and difference in perceiving the specific behavior of a child when using AAC, the child is reported to suffer from learned helplessness and lose a desire of communication: *"My child doesn't want to use AAC at home, because he often gets tired when assisted with a different style of organizing AAC (compared to the teacher.)" (P2)*

Design Implications

Our findings from the interviews imply that several impediments to a balanced participation and the inefficient process of collaboration undermines successful and consistent collaboration between caregivers. However, current AAC technologies are limited in that they do not provide support for overcoming these challenges. To address this, we aim to incorporate the assistance toward the collaboration among caregivers in the AAC system. In order to identify design elements that might support caregivers to actively collaborate and help children use device easily, we drew the following design implications for the collaborative AAC system.

First, a system should scaffold the process of sharing observations and calibrating different opinions for caregivers. Second, a system should induce the balanced participation of caregivers. Third, consistent and contextualized formats for symbol arrangement might help collaboration among caregivers.

Interestingly, one of the results we gained from the interview was the need of *contextualizing* child utterance in an AAC device. From various reports over the difficulty of teaching and referencing child conversations in the current grid based AAC layout, we could identify that giving contextualized forms of conversation might help caregivers to avoid misunderstandings and more easily reference a child communication scene. This requires understanding of the main communication goals, which is mutually acceptable among child and caregivers. From the findings on the AAC usage of a child we gained from the interview, we yielded and summarized the following communication themes.

1. **Expressing Action.** Caregivers notified that expressing actions constitutes a large portion of the communication of their child. They use simple verb and noun combinations to express their needs. As combining a core word (verb) and a fringe (mostly nouns) is reported to increase the frequency of AAC use [5], displaying both core and fringe words as an organization can facilitate the AAC use of a child.
2. **Sharing a prior/future schedule.** A lot of children with developmental disabilities such as Autism Spectrum Disorder are known to have difficulty perceiving time ordered events. We found that caregivers consider it very important to share a time-ordered schedule in child-to-caregiver communication using AAC, because they need a method to help children easily understand schedule changes before the children get confused. Plus, caregivers consider schedules as an initializer of most conversations.
3. **Asking for a choice.** Caregivers reported to actively utilize a grid-layout in order to show their children and ask for a choice among symbol candidates. They considered a grid layout as the simplest and fastest method of communication, and interviewees reported using AAC mainly for expressing basic choices. This is supported with the report that expressing basic needs constitutes the largest portion among various purposes of AAC use [15].

DESIGN OF TALKINGBOOGIE

In this section, we present the design of TalkingBoogie consisting of two mobile applications: TalkingBoogie-AAC and TalkingBoogie-Coach. TalkingBoogie-AAC supports communication between children and their communication partners, while TalkingBoogie-Coach supports collaboration among the caregivers. The overall process of using TalkingBoogie is shown in Figure 1 and elaborated in the following subsections.

TalkingBoogie-AAC: Easy-to-use Mobile AAC Application for Children and Caregivers

Existing AAC systems typically require users to construct sentences by arranging the symbols by themselves, which was reported to burden the caregivers guiding children as well as the children. Furthermore, caregivers lack a consistent way to reference a specific scene of conversation with the child when discussing it with others. TalkingBoogie-AAC tackles these difficulties by extending the existing AAC with predefined layouts for symbol arrangement. Inspired by our design implication, we aimed to design consistent and contextualized layouts that reflect the common communication goals of users. On such an account, three symbol layouts were derived from the main communication goals identified in the preliminary study. Figure 4 shows the layouts, each of which reflects a certain goal of communication.

1. **Action layout** depicts action-related communication (Figure 4c). To facilitate the use of the layout, it contains spaces for both core and fringe words. Users can input one core word (e.g. verb) and up to three fringe words (e.g. noun) to express action with specific objects among up to three candidates (e.g. Eat: Hamburger, Pizza, Noodle.)
2. In **schedule layout**, users can input up to ten symbols in time-order (Figure 4d). Each symbol describes the specific event, and caregivers can make a card depicting a periodic schedule (e.g. Monday: Home → Bus → School → Hospital.) If the specific schedule changes, they can edit a single symbol of the changed event in the card.
3. The third layout, **choice layout**, is the most similar layout to the existing grid layout (Figure 4e). It contains up to 12 symbols, and the symbols are automatically resized to fill the screen size by the number of symbols. The title of its layout is the name which can represent the category of every symbol (e.g. Lunch: Noodle, Pizza, French Fries, Chicken.)

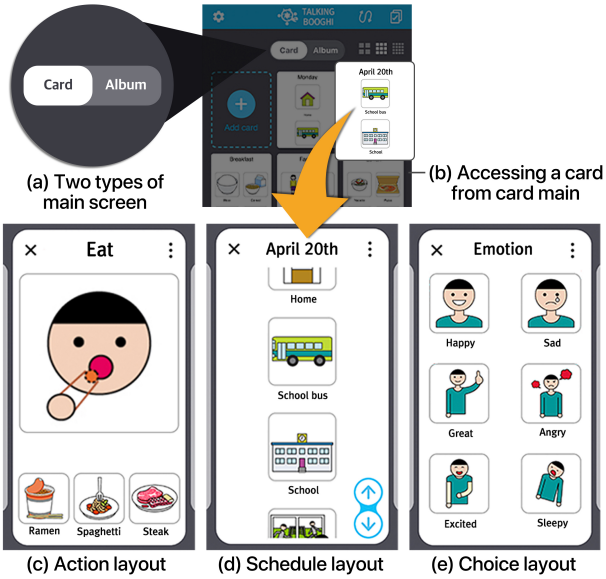

Figure 4. The overview of TalkingBoogie-AAC featuring three layouts

When teaching the children, caregivers might use these layouts as a basic utterance unit for children to begin with, rather than leaving children to manually compose symbols and teaching them all the way from the bottom. Caregivers and children can create a *conversation card* by filling up symbols in a layout. Once a conversation card is constructed with the layout, it is saved and displayed on the main screen for future use. To help users search cards they want, TalkingBoogie-AAC lets the users easily classify the symbols and saved cards into different albums. For those children having difficulty perceiving the concept of categorization, we let users choose a *card main* where children can scroll down and directly access to a card (Figure 4a). Also, when caregivers discuss their AAC usage with other caregivers, these formats serve as a consistent way of referring to a certain context of communication. Ultimately, such consistency helps prevent the damaging effects on the children from the confusion arising when there is discrepancy in the strategies of caregivers.

TalkingBoogie-Coach: Supporting Collaboration between Caregivers

Caregivers, parents who are not used to AAC intervention in particular, are often confused and not knowing what to observe and how to record it. They also find it hard to achieve a consensus on intervention strategies. In particular, such caregivers unfamiliar with AAC like parents tend to lose motivation and

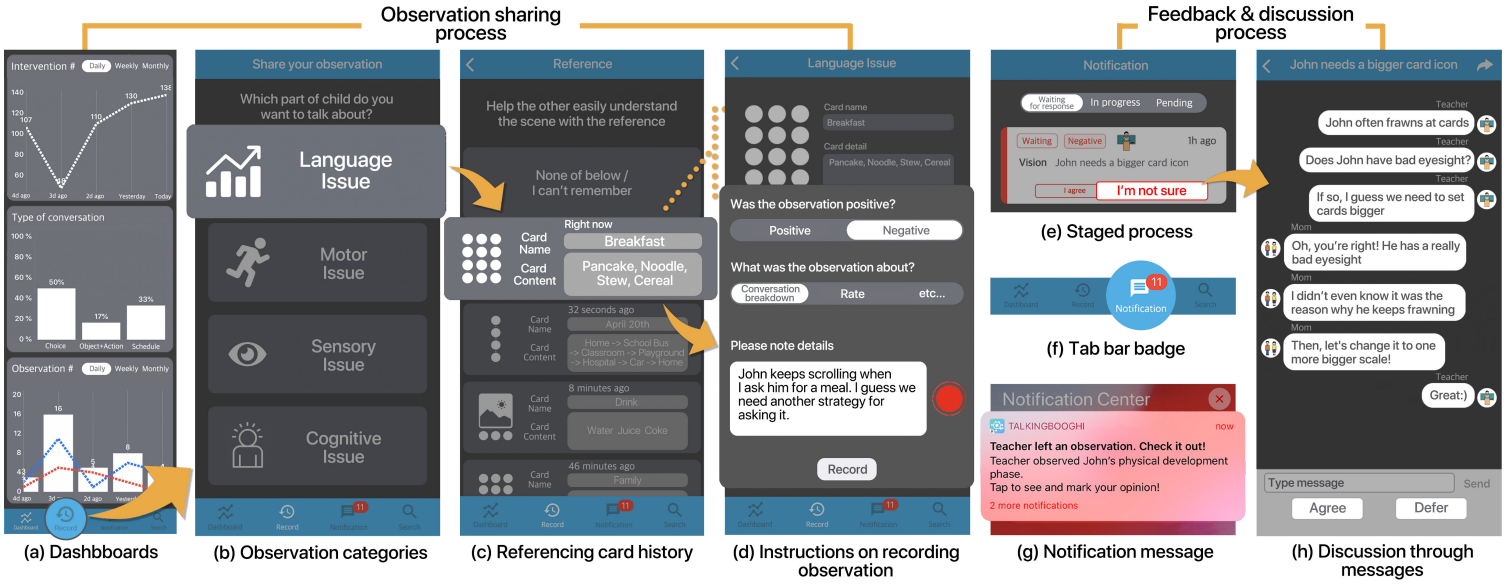

Figure 5. The overall interface and usage flow of TalkingBoogie-Coach. (a) Dashboards (b) Observation categories (c) Reference of child communication (d) Template for recording observation (e) Stages for records (f),(g) Design elements that induce caregiver participation (h) Messenger for a discussion

often end up shifting duties to teachers, who suffer from extreme burdens. To cope with these difficulties, we designed a collaborative system that scaffolds the process of sharing observations and calibrating different opinions, while at the same time induces balanced participation. Figure 5 shows the overall interface and usage flow to support the collaboration between parents and teachers.

Recording observations

TalkingBoogie-Coach allows caregivers to record their child observations anytime. To guide the caregivers to carry on a meaningful and coherent observation, TalkingBoogie-Coach provides a systematic template to base their record.

The template informs a caregiver to first clarify the type of observation among four categories: language, motor, sensory, and cognitive observations (Figure 5b) [24]. After selecting a category, TalkingBoogie-Coach prompts three instructions which enrich the content of the record (Figure 5d). Specifically, these instructions include: "Is the observation positive or negative?", "What is the observation about?", and "Please note the details." For the question of what the observation is about, depending on the category the caregivers choose, different options are shown as an example. For instance, if the caregiver chooses the 'language' category for classifying the observation, TalkingBoogie-Coach would return 'conversation breakdown' and 'rate' as sample answers.

This process of guiding the caregivers to record and articulate their observations is a stepping stone to efficient collaboration, as it serves as a basic guideline for what to observe and how to record it. With the help of TalkingBoogie-Coach, the records can naturally be shared with other caregivers, and their consistent format allows them easy to be easily understood and further discussed. Plus, TalkingBoogie-Coach is automatically synced with TalkingBoogie-AAC so that the caregivers can easily refer to a card in TalkingBoogie-AAC that represents a certain utterance when recording an observation (Figure 5c). This feature allows the caregivers to more clearly convey the context of the observation they want to mention.

Resolving an issue

The records are classified into four stages: waiting for a response, in progress, pending, and verified. Once a record is created, it is listed in *issues* tab, where the caregivers can check the records made by each other (Figure 5e). The default state of the record is set as *waiting for response*.

Then, other caregivers can give feedback on the record by selecting either *I'm not sure* or *I agree*. If the former is chosen, the state of the record is changed into *in progress*, and the system opens a debate (Figure 5h). The caregivers may discuss the observations and employed strategies that are mentioned in the record until they reach a consensus and convert its state to *verified*. If it is unlikely to arrive at an agreement, they can temporarily set the state of the record as *pending*. In this way, the communication channel for discussion is separated for each issue, allowing the caregivers to focus on a single issue at once. Contrarily, if *I agree* is chosen, the state of the record turns into *verified* immediately, and the record will appear in the *search* section. Caregivers can later check the previous strategies when they cannot remember them in the search section. As such, TalkingBoogie-Coach scaffolds the structured process of collaboration, and facilitates the creation of a shared understanding among the caregivers towards establishing personalized strategies that are consistent across various settings.

On the bottom of the application, a badge on the *issues* tab indicates that the number of records for which the state is *waiting for response* (Figure 5f). The badge is intended to give the caregivers an impression that they need to review the observations of the counterpart, thereby inducing their active participation in collaboration.

Group ID	Child age (Gender)	Child Diagnosis	Child's Communicative Mode(s)	Role	Description / AAC experience
G1*	8 (M)	PDD-NOS	Low-tech AAC (Symbol boards) + Tablet AAC app	Child	Skilled at using smart devices
				Parent	1y
				Teacher	4y
G2*	9 (M)	Autism Spectrum Disorder	Low-tech AAC (Symbol boards) + Tablet AAC app	Child	Low hand motor ability
				Parent	6m
G3	13 (F)	Autism Spectrum Disorder	Non-aided AAC (Gesture)	Child	Low hand motor ability
				Parent	3y
				Teacher	6y
G4	7 (F)	PDD-NOS	Non-aided AAC (Gesture) + Mobile AAC app	Child	-
				Parent	1y
				Teacher	3y

Table 1. Participants of the evaluation *A single teacher (G1/2-T) participated in G1 and G2 at the same period

Reviewing the overall activity

For AAC intervention to be successful, caregivers should continuously observe and support the child with consistent strategies throughout a variety of settings [16]. Hence, TalkingBoogie-Coach sends a message to a caregiver when a record is recorded by the counterpart, then the counterpart responses to the record, and the new message in discussion progress is received. This approach induces active caregiver participation by synchronizing every caregiver in the observation sharing and discussing progress.

TalkingBoogie-Coach tracks the data of cards that were accessed in TalkingBoogie-AAC and visualizes in the dashboard (Figure 5a). Such visualization of the caregiver usage history influences individual participation; demonstrating a clear gap in their usage rate that can motivate the inactive caregiver.

Furthermore, the dashboard also shows graphs indicating the relative usage of each layout and the number of observations recorded. Also, the number of positive and negative observation records are shown in the graph respectively, along with the total. With the information visualized on the dashboard, caregivers can grasp the recent tendency of communication patterns that the child has exhibited.

System Implementation

Both TalkingBoogie-AAC and TalkingBoogie-Coach were implemented on the iOS deivces. The usage log and caregiver strategies logs are uploaded to a Firebase server, and the caregivers are notified with a message once the counterpart caregiver sends a message or submits a new strategy. To ensure privacy when collecting user data, every data is uploaded on the server with an anonymous identifier.

We adopted an Ewha AAC symbol system, Korean-based symbol illustrations, for our symbol display [31] in order to support children in successfully delivering region-specific ideas. Other customizing features for making it accessible to a wide range of children were included in TalkingBoogie-AAC, such adjustable text-to-speech (TTS) speed (0.5~2.0x), customizable main screen column size (2~4), and a *scroll up, down* button for scrolling the view.

EVALUATION

To identify if our system successfully reflected the design implications, we ran a two-week deployment study with four target groups, each of which consisted of a child with a speech impairment, a parent of the child, and a classroom teacher.

Participants

We first recruited teachers of non-verbal children by delivering our experiment documents to the local special-education schools. Then we asked parents of children, whose teachers showed intention to participate, to participate in the experiment. For five groups whose parents and teachers both agreed on participation, we finally asked the intention of the child using AAC, and excluded one group whose child refused to participate. As a result, four groups with a child aged from 7 to 13 years were recruited, listed on Table 1. As we developed our mobile system in the iOS environment, we required caregivers to have at least one-month of experience using iOS devices. The procedure was evaluated and approved by the Institutional Review Board (IRB) of the university, and each caregiver in the study was compensated approximately $50 per week.

Procedure

Due to the limited number of participants and difficulty of recruiting non-verbal child with caregivers groups, we identified the extreme difficulty in performing a large-scale deployment. Instead, we conducted an in-depth analysis focusing on a small number of caregivers using TalkingBoogie to identify initial insights on supporting collaboration between caregivers. To minimize the risk of overgeneralizing the behavior and effects, such as social desirability or novelty biases [13], we remotely conducted surveys and data collection.

First, we offered each participant an Apple iPhone 7 device with the TalkingBoogie system pre-installed. We also provided every caregiver with a manual explaining how to use TalkingBoogie, and introduced the instructions of the experiment. Then, the caregivers were given enough time to customize the TalkingBoogie-AAC by creating default cards that reflect the common conversation topics per child. Each caregiver was then asked to answer a survey. In the pre-survey, caregivers

self-rated the cognitive load using NASA-TLX and the percentage ratio of their participation in collaboration until now.

During the two-week deployment study, caregivers were asked to freely use the system without any control. Usage data on weekends, when children are not going to school, were not used in the analysis (10 days of data collection). Caregivers also answered four surveys at the regular interval of three days. The four surveys asked each caregiver to rate her cognitive load and the level of consensus with her counterpart caregiver on a 10-point scale.

After the two-week period, we conducted a post-interview with each participant about the experience of using each feature, in addition to requesting feedback on the design of TalkingBoogie. The responses were all transcribed, and two authors analyzed the scripts via open-coding and iterative clustering. Also, we ran a post-survey with questions identical to the pre-study survey on the deployment phase to identify if there is any difference in the reports of the caregivers.

RESULTS

Usage Pattern

During our deployment study, the number of card access[2] by children in TalkingBoogie-AAC was 68.08 times (SD = 26.59) on average per day in the home setting, while the number in the school setting was 41.15 times (SD = 16.38). As shown in Figure 6, all groups most frequently accessed the cards on the first day of the experiment to customize the application settings at the beginning, and afterwards the rate remains fairly consistent with minor fluctuations over time. No group showed any discontinuance or significant decrease under uncontrolled circumstances.

In TalkingBoogie-Coach, parents created 19.0 records (SD = 8.2) per day on average, whereas teachers left 23.3 records (SD = 8.8). In total, parents recorded 77 observations, and teachers created 92. Among these records, 24.3% (41 records) were marked as *I'm not sure*, and went through a discussion progress due to disagreements or questions regarding the observation. 47%, 9%, 11%, and 42% of the observations were categorized as language, motor, sensory, and cognitive issues, respectively.

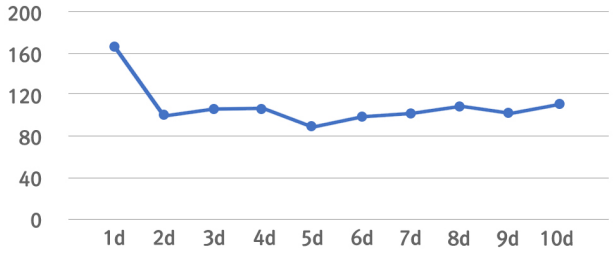

Figure 6. Four group's average number of daily card access

Balancing the Participation of Caregivers

Comparing the pre- and post-survey results, we identified a major shift in the relative participation rate of caregivers (Figure 7). The participation ratio of parents showed a significant increase ($t = -2.954$, $p < 0.05$) from 27.5% (SD = 9.60) on average to 47.5% (SD = 9.60). In contrast, the participation rate reported by teachers significantly decreased ($t = 3.889$, $p < 0.05$) from 83.3% (SD = 15.3) on average to 48.9% (SD = 11.7). This change towards balanced participation was identified in all four groups. In fact, such a change corresponds with the actual number of records by each caregiver. Among the total 169 observations recorded during the two weeks, 45.6% were made by parents, while 54.4% were made by teachers. Along with these results, the interview reports also indicated that parents started to actively take part in the collaboration.

"I was a bit surprised that the parent was eager to participate in because I taught and prepared every strategy for G4-P before I started the experiment." (G4-T)

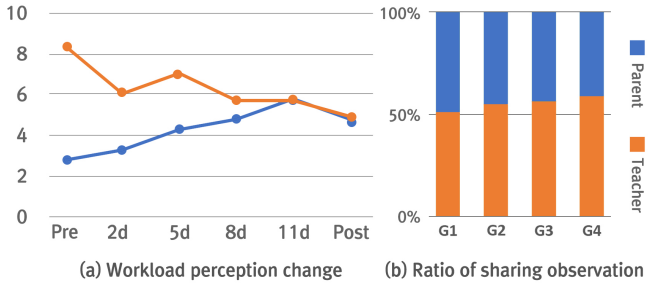

Figure 7. Parent/teacher group's (a) Perceived participation ratio (pre / phase 1~4 / post survey) (b) Actual participation (observation sharing) ratio in evaluation

Self-reflective participation

The findings from the interviews suggest several factors that helped induce balanced participation. First of all, two caregivers responded that reviewing their previous contributions with the dashboard in TalkingBoogie-Coach helped them avoid falling into mannerisms. For instance, visualizing changes in the number of negative observations prevented a parent from overlooking any difficulties.

"I realized myself having been habitually overlooking certain communication issues. It became clear to me that something should be done when I saw a clear increase in the number of negative observations." (G2-P)

Increase in mutual awareness

Parents pointed out the increase in mutual awareness as another main reason for their increased participation. To a question asking what motivated them to record an observation, three out of four parents responded they were motivated when identifying the active participation of the teacher. The explicit visualization of the usage history of each caregiver in the dashboard was a major source of seeing the participation of the counterpart, and created mutual influence between caregivers.

"Whenever I could see from the graph that the teacher had left new observations, I also began to think that I should also record some more." (G1-P)

Furthermore, TalkingBoogie notifies of updates made by the counterpart. With the help of notifications, the caregivers were able to form a strong mutual awareness and were consistently involved in collaboration.

[2]The number of card access is incremented when the user i) clicks a card and ii) clicks at least one symbol in the card.

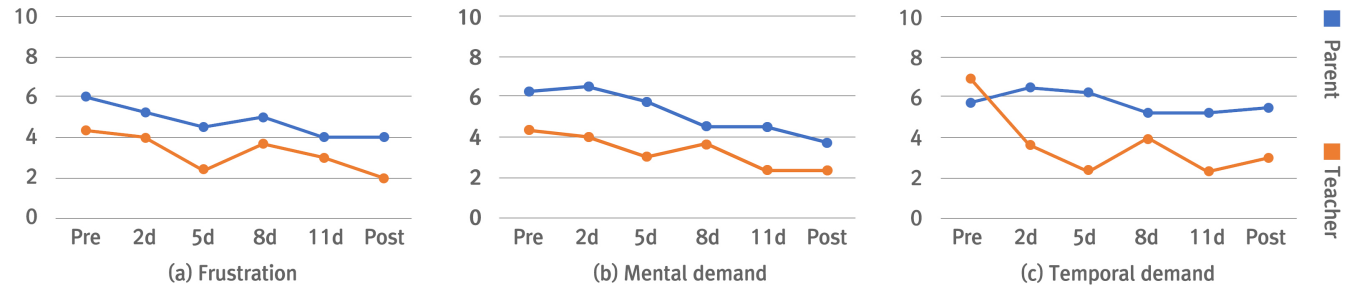

Figure 8. Parent/teacher group's average workload index in the six surveys

"The notifications and dashboard clearly imprinted on my mind that I was not doing this alone but together with the teacher, which made me more willing to participate. (G3-P)"

Clear identification of the effects of interventions

Interestingly, the results showed that a structured process of collaboration is effective, not only in terms of efficiency but also to promote active participation. By recording and discussing the observations in a partly uniform way, caregivers could easily review and search previous activities with the help of TalkingBoogie-Coach; this made it possible to clearly discern the effects of their intervention strategies. Moreover, through discussing each observation in a separate thread, the effects of strategies in the communicative abilities of the child could be clearly identified, acting as a powerful stimulus.

"Before, I had so little knowledge that I had no idea what to do . . . my child started to get used to the day concept with the 'day of the week' card . . . I could get clear insights on what I should do, which in turn let me more actively participate." (G2-P)

Effectiveness of TalkingBoogie Symbol Layouts

Ease of teaching sentence construction

One of the causes that limit the involvement of parents was that parents are not accustomed to teaching sentence construction using AAC. The three layouts for symbol arrangement in TalkingBoogie-AAC not only act as a guide for parents, but also prevent misunderstandings among caregivers that arise from inconsistency when referring to a certain conversation. Six out of seven caregivers reported that the layouts in TalkingBoogie-AAC properly reflect the major communication goals with their child. The layouts showed a fairly even distribution of usage to each other (Table 2).

There was a positive shift in the caregiver answers to the survey question asking how easy it was to guide the child in constructing a sentence using AAC. In the surveys, both parents (pre: 2.25, post: 5.75, $t = -2.898$, $p < 0.05$) and teachers (pre: 4.33, post: 8.00, $t = -11.000$, $p < 0.05$) reported a significant increase in the ease of teaching sentence construction. In particular, all four parents, who do not have expertise in AAC education, showed such an increase. Three parents and two teachers attributed these positive changes to the layouts in TalkingBoogie-AAC in the interview.

	G1	G2	G3	G4
Action	34.25%	31.08%	45.28%	38.89%
Schedule	32.41%	31.08%	24.53%	29.63%
Choice	34.25%	37.84%	30.19%	31.48%
SD	1.00	3.90	10.73	4.90

Table 2. Four group's ratio of each layout used for creating cards

"It was hard to help my child express action concepts before, because a verb was a vague concept for her . . . In action layout, the verb is shown larger than others, so I could easily induce the child to focus more on and understand the concept." (G4-T)

Consistent and contextualized reference

Caregivers reported that all three layouts acted as *conversational materials* between caregivers. Based on the mutual awareness of the layouts, caregivers could easily refer to a specific situation while discussing it with each other.

"We (G3-P, T) liked schedule layout so much . . . we know that the second (schedule) layout depicts a schedule so we could easily make a card with it after talking about it." (G3-P)

On a similar note, caregivers reported that TalkingBoogie-Coach enables efficient discussion by allowing them to refer to a specific card created in TalkingBoogie-AAC when recording observations. By including the actual trace of the behavior, the caregivers were able to clearly convey the context, which helped to reduce misunderstandings and ultimately their burden of resolving those misunderstandings one-by-one.

"It was hard for me to remember every single detail to share. . . . TalkingBoogie-Coach showing the history of conversations with my child helped me easily recall the situation." (G1-P)

Scaffolding the Process of Sharing and Discussing Observations

Increased understanding of what to observe and record

Parents tend to overlook the importance of observations, thus they do not share them in many cases. Recording observations using TalkingBoogie-Coach was helpful to keep parents aware of the significance of observations, providing guidance on what to observe and how to record it. For one, four categories in the template encouraged the parents to pay attention to various aspects of a child. Furthermore, the template for observation in TalkingBoogie-Coach guided the caregivers to enrich the content of the records. Two parents and one teacher reported that the examples given and questions prompted in the template helped them elaborate on the observation and include the necessary details that they had neglected before.

"I used to check only the language abilities of the child, but now I also check many other aspects such as his physical abilities. I realized for the first time that his hand movements have improved a lot." (G3-P)

"In order to write observations precisely based on the lists of the template I have to check when leaving an observation, I get closer and interact more with the child. (G3-T)"

Efficiency of the process of collaboration

By following the process in TalkingBoogie-Coach, the caregivers were able to reduce the inefficiencies. Such improvement helped reduce the overall frustration level, along with reducing the mental and temporal demands on the caregivers. Their mental demands steadily decreased from 5.43 (SD = 1.81) to 3.14 (SD = 1.46) on average after the experiment. On a similar note, the temporal demands decreased from 6.29 (SD = 1.80) to 4.43 (SD = 2.23). The caregivers also reported their frustration level as 5.29 (SD = 2.21), which then declined to 3.14 (SD = 2.34).

TalkingBoogie-Coach syncing with TalkingBoogie-AAC, providing a formulaic template for recording observations, and supporting a staged discussion where there is a separate communication channel for each issue; this largely contributed to improving the efficiency of the overall collaboration process.

"The overall process became more efficient in that using AAC itself, observations, and discussion channels could be all seamlessly connected to one another." (G3-T)

Increased level of consensus

Six out of seven caregivers showed a clear increase in their level of agreement over the intervention strategies. The responses to a question asking to what degree they agree with their counterpart indicated a gradual increase from 5.57 to 7 on average over time. The teachers in particular, who used to take control of most of the work in collaboration, showed a steeper increase from 4.67 to 6.67 on average.

As observations of the teachers and parents are respectively confined to certain settings, they were knowledgeable about only a fraction of the communication of the child. By sharing their knowledge thoroughly using TalkingBoogie-Coach, caregivers were able to learn about the behaviors of the child in various settings that they were previously unaware of. With the shared knowledge, caregivers were able to keep their intervention strategies consistent. In fact, a parent and teacher in the same group reported many strategies in common.

"The child (G2) sometimes keeps clicking a symbol of a cup. I asked his mom, and she shared that he clicks it when he doesn't want to drink milk with a straw . . . I created a 'drink → straw, cup' card in action layout for him." (G1,2-T)

DISCUSSION

Recognizing a Child's Communicative Competence

By emphasizing the child's *communicative competence* in AAC-aided communication proposed by Light [21], Ibrahim et al. reported that caregivers' low expectation on children limits the development of communicative competence of the child [17]. From the interviews, we could identify several caregivers' reports trying to explore a child's communicative competence and help children develop it with the counterpart caregiver. For example, G4-T reported that she used to discipline the child for making noises. However, using TalkingBoogie-Coach, she began to observe the *intention* of the child in order to share it, and found out that the child tried to communicate about TV programs by drawing an attention. On such an account, TalkingBoogie-Coach directly and indirectly helped caregivers to realize that communication abilities of child is not static but developing. By positively altering their perception, TalkingBoogie-Coach could motivate caregivers to keep exploring various aspects of child's communication and not to underestimate child's potential.

Extension to Diverse Caregivers

In our evaluation, we mainly targeted mothers and teachers, who are the typical long-term caregivers of non-verbal children. Due to culture influences, particularly in South Korea, holding mothers mostly responsible for childcare [29], all parents who participated in our study were mothers. Although our deployment study tackled only the collaboration between a mother and a teacher, we believe that TalkingBoogie can be extended to support caregivers other than mothers and teachers (e.g., stay-at-home fathers), as well as collaboration that involves more than two caregivers. Furthermore, to prevent the role of parents from being disregarded as mere informants [11] when collaborators increase, one possible approach is to make participation of long-lasting caregivers as a requirement for the system to proceed to the next stage. On a similar note, by assigning different weights for each caregiver when discussing the intervention strategies, it would be possible to strengthen family members as equivalent decision-makers.

Caregiver in Charge of Multiple Children

In classroom settings, it is common for special education teachers to take care of multiple children with special needs at the same time. In our deployment study, we asked G1/2-T to use TalkingBoogie with two children with different levels of communication in the same environment. In the post-interviews, as she managed multiple children at once, she reported that she sometimes confused one child from another and even left observations about the other child for once. Such mistakes are detrimental to collaboration since parents might get hurt by drawing a comparison of the children. To prevent such confusion, it may be possible to extend the 'search' section to allow caregivers to integratively search among records about each child. Also, future designs may increase the visibility of the information of a child to prevent confusion.

Limitations & Future Work

One limitation of our deployment study is the small number of participants due to the extreme difficulty of recruitment that is known as a prevalent issue in AAC research [26]. Furthermore, although two-week deployment provided valuable insights into supporting collaboration between caregivers, evaluating TalkingBoogie with more participants for a longer period of time may be needed in terms of generalizability. As such, we plan to distribute TalkingBoogie and gather long-term data.

CONCLUSION

In this paper, we designed and evaluated TalkingBoogie, a collaborative AAC system that supports multiple caregivers to actively participate in the AAC-aided communication of a child. With two mobile applications, TalkingBoogie balances

the participation of caregivers in collaboration and scaffolds the overall process of sharing and discussing observations on children. Through a two-week field evaluation, we could identify the feasibility of a collaborative AAC system.

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