Robot-based Augmentative and Alternative Communication for Nonverbal Children with Communication Disorders

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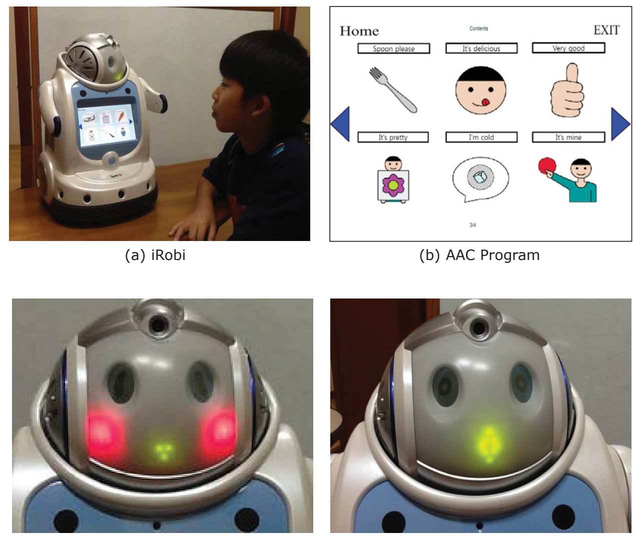

(a) iRobi (b) AAC Program (c) Shy motion (d) Speaking motion

Figure 1. (a) Child using iRobi, (b) the AAC program shown on the robot screen, and (c,d) different facial expressions of reaction.

ABSTRACT
Nonverbal children with communication disorders have difficulties communicating through oral language. To facilitate communication, Augmentative and Alternative Communication (AAC) is commonly used in intervention settingss. Different forms of AAC have been used; however, one key aspect of AAC is that children have different preferences and needs in the intervention process. One particular AAC method does not necessarily work for all children. Although robots have been used in different applications, this is one of the first times that robots have been used for improvement of communication in nonverbal children. In this work, we explore robot-based AAC through humanoid robots that assist therapists in interventions with nonverbal children. Through playing activities, our study assessed changes in gestures, vocalization, speech, and verbal expression in children. Our initial results show that robot-based AAC intervention has a positive impact on the communication skills of nonverbal children.

Author Keywords
communication disorder; Augmentative and Alternative Communication (AAC); robot; language therapy.

ACM Classification Keywords
J.3 Life and Medical Sciences: Health; H.5.m Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
Communicative ability is a very important and necessary part of our daily lives. However, many children who have difficulties with communicative expression can have limited or no verbal capability and often require augmentative and alternative communication (AAC) [8]. These children are often found to be deficient in their language acquisition, including both receptive and expressive language skills. The goal of AAC is to aid such children in communication by augmenting their verbal output by providing an alternative way to express their needs and thoughts. AAC users present a range of abilities from normal intelligence with physical disability to severe mental disability; there are also individuals with autism [8]. Children with delayed language acquisition are often defined as children with receptive and expressive language development delay of more than 1 year in comparison to chronological age. Children with minimal verbal skills, amongst children with language delay, are defined as children whose normal range of expressive language is limited to fewer than 20 words. As a result, such children mainly communicate using limited expressive words and non-linguistic modalities.

Different forms of AAC have been used and include different devices that are targeted for people of all ages and with different degrees of disability or communication difficulties [6, 8, 14, 15]. However, recent study [16] has shown that it is not necessarily a particular device or a particular application that has the best effect; rather, individual preferences (and needs) are more important. In this study, we evaluate the use of a robot as an alternative tool for AAC and

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study the impact of robot-based AAC on nonverbal children with communication disorders. Our goal is not necessarily to compare different forms of AAC but to evaluate the impact of robot-based AAC. We exploit the fact that robots can appeal to young children and we leverage robots during the intervention process. Our results are promising as they show that robot-based AAC was able to improve the communication skills of children during the intervention phase. In addition, the communication skill improvements of the children were sustained following the treatment/intervention phase.

ROBOT-BASED AAC

Traditional AAC technologies do not have strong appeal to young children and are challenging for young children to learn to use [14]. Therefore, in order to enhance the positive effects of AAC interventions for young children with communication disorders, an alternative AAC technology/application is necessary. Light and Drager [14] proposed that enhancing the appeal, expanding the functions, and reducing the learning demands of AAC technologies are necessary for children with communication disorders; they determined that AAC should be redesigned. They recommended five features to enhance the appeal of AAC technology for young children with communication disorders: function, color/light, shape/appearance, output, and personalization. To communicate successfully with their peers in mainstream or school settings, young children were motivated to interact with their peers. To use more AAC technology, the shape and appearance of AAC technology must be familiar to both AAC users and their peers.

In this study, we used an intelligent humanoid robot as a new AAC device for young children. The Intelligent Humanoid robot's face looks similar to a child's face; the robot responds to children's touch and can sense the distance between the child itself. The robot also has multi-functional sensors that can be used to motivate children to initiate social communication. Recent study [10] has shown that humanoid robots, similar to the robots that were used in this study, were a more effective tool than tablet PCs for children with high-functioning autism when a story re-telling task was evaluated. In this work, our intent is not to suggest that robot-based AAC is necessarily better than other AACs. Instead, our focus is to propose robot-based AAC because an alternative AAC device because it was shown to be effective in the children who were evaluated as part of this study.

We used iRobi [26] (Figure 1(a)); the size of the robot was approximately 450 × 320 × 320 mm with a 190 × 120 mm touch screen. iRobi has microphones, cameras and speakers and, thus, can recognize sounds and the actions occurring in the nearby environment; it can also speak sentences. It can react by changing its facial expression with eyes, mouth, and cheeks, or through its movement. The robot can be controlled by smartphone through Wi-fi connectivity; this capability was used by the therapist during the intervention phase of our study. The iRobi that we used in our study is not the most technologically advanced robot; however, we used iRobi because it was readily available for our study and the size of the robot was reasonably small such that it was not intimidating to the children.

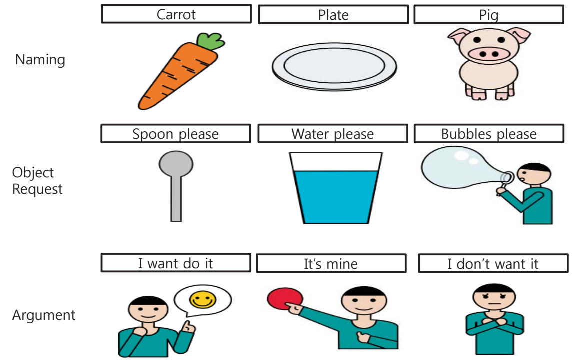

Figure 2. Examples of different symbols used in the study.

The AAC program used was written in Adobe Flash but a simplified user interface was created such that the symbols and words could be easily edited directly on the screen by the therapist. A snapshot of the AAC program is shown in Figure 1(b). Because of the limited screen size, 6 symbols were shown on one page. When children touch a symbol, language that describes the symbol is spoken by the robot. The screen has arrows on the sides to allow scrolling between different pages of symbols. In our study, we used a total of 12 symbols for each child; examples of the different symbols used are shown in Figure 2. The expressions and symbols are a very important factor in AAC, especially since the participants do not fully understand language.

The symbols should be composed of words that are easily understandable and important for the children to learn. The symbols were determined after a pre-study meeting with the parents to determine which symbols would be appropriate for the children and which words the children were familiar with. The following procedure was used to identify the symbols.
(1) The children were examined with the Korean MacArthur-Bate Communicative Development Inventories (K M-B CDI) [1] [23] test to determine which words they know.
(2) Necessary words to carry out the play activity were identified.
(3) The words that overlapped between steps (1) and (2) were selected.
(4) The final symbols/words were determined after a meeting with the parents.

METHODOLOGY

Participants

For our study, four children were recruited from the Children's Center for Developmental Support in Seoul, Korea (Table 1). All participants met the following AAC selection criteria [11]: – (a) they were pre-school children, (b) they had vision, hearing, and motor abilities that were functional for participation in the study according to their parents' reports (i.e., they could see the AAC screen, hear the instructor or robot during sessions, and touch the AAC screen with their

[1] The Korean MacArthur-Bate Communicative Development Inventories(K M-B CDI) is based on the MacArthur-Bate Communicative Development Inventories (http://mb-cdi.stanford.edu/) which is commonly used for assessing language and communication skills.

		Child 1	Child 2	Child 3	Child 4
Age(gender)		5y 4m(M)	2y 9m(M)	6y(M)	4y 4m(M)
Major communicative modality		Gesture, Vocalization	Gesture, Limited verbal	Gesture, Vocalization	Gesture
Communicative ability	**Request**	Gesture	Gaze	Gesture	Gesture, Vocalization
	Protest	Gesture	Gesture	Non-appearance	Non-appearance
	Claim	Non-appearance	Gaze	Non-appearance	Non-appearance
Observed action		Crying when he wants something or taking sombody by the hand	Expression by eyes and nodding	Expression by eyes and gesture	Taking somebody by the hand with speaking
			Can make 2-3 syllable restricted words	Can speak vowels but not consonants	
		Understands simple verbs and nouns	Understands simple verbs and nouns	Understands simple verbs and nouns	Understands simple verbs and nouns
Comment		PDD-NOS	PDD-NOS	PDD-NOS	Autism

Table 1. Child participant characteristics, including age, gender, communication ability, and observed action.

fingers), (c) they had a total number of expressive words that was fewer than 20 as indicated by the K M-B CDI [23], and (d) their language development was delayed by more than 1 year as indicated by the results of the Korean Preschool receptive and expressive language test [25]. Table 1 describes the recruited children. They range from 2 years 9 months old to 5 years 4 months old.

All of the children were characterized as having *pervasive developmental disorder* [1], which includes developmental delay in communication and socialization. In particular, children 1, 2, and 3 were diagnosed with PDD-NOS (Pervasive developmental disorder not otherwise specified), while child 4 was diagnosed with autism. PDD-NOS diagnosed children show severe impairment in the development of reciprocal social interaction or verbal and nonverbal communication skills [1].

The study was carried out for approximately 6 months between March 2013 and August 2013 at the Children's Center for Developmental Support, which is affiliated with a university in Korea. Before the actual experiment, a preparatory phase was carried out in which we interviewed the children's parents; we also provided opportunities for the children to familiarize themselves with the facility for the experiment.

Single Subject Design

A single-subject, multiple-probe design was used across participants to examine the effects of robot-based AAC intervention on communication expression of nonverbal children. The experiment consisted of three phases: (1) baseline, (2) intervention, and (3) maintenance. The multiple-probe design [22] is a variation of multiple-based design, in which intermittent data is collected during the baseline phase. Prior work [13] has shown that intermittent probes can avoid inappropriate subject behavior frequently associated with an extended baseline. Using a multiple baseline or probe as a control measure is useful to examine the effects of treatment on behaviors for the developmentally disordered children [18, 24].

A single-subject design has been used to evaluate the effects of less strictly behavioral interventions in fields such as clinical psychology, speech-language pathology, and social work [18]. The single-subject design in this work involves behavioral oriented intervention with a robot-based AAC program. Measurements in single-subject design occur repeatedly over time as participants proceed through the different phases (e.g., baseline, intervention, maintenance) of the study. This allows for ongoing evaluation of the participants' behavioral performance, as well as a determination of when to change phases. Most single-subject designs begin with an initial (or baseline) phase during which the planned intervention is not implemented. The objective is to understand the participants' performance under typical conditions. The baseline phase provides a pattern that allows us determine how the children's communication expression would continue if no intervention was implemented. Once the data are relatively stable, the intervention can be implemented. The different phases are described below.

Baseline phase – This phase consisted of 10 minute sessions and simple activities (such as mealtime activity, bubble activity, or train activity) that were carried out between the children and the therapist. Robot-based AAC was available in the room (Figure 3(a)), but no intervention was provided for the children in this phase.

The goal of the activities was to encourage communication with the children. Each child completed a minimum of three baseline sessions in order to ensure that stable baselines were attained; stability was defined as no more than 3 times fluctuation of performance.

Intervention phase – Once a stable baseline was established for child 1, intervention phase began for child 1, while the remaining children remained in the baseline phase. Once the intervention for child 1 was seen to lead to improvement (defined as 3 consecutive sessions of improvement), child 2 entered the intervention phase with the remaining children still in the baseline phase.

In a single-subject design with an often limited number of participants, it is important to determine that the participant improvement is coming from the intervention itself and not from other factors. For example, if all the children moved into the intervention phase and showed improvement, it is not necessarily clear if the improvements are coming from the intervention itself or from another external source or sources – e.g., general improvement over time, familarity with therapists, etc. As a result, after child 1 moves into the intervention phase, child 2 continues to remain in the baseline phase and only enters the intervention phase when child 1 shows improvement. Similarily, child 3 and child 4 also enter intervention when the previous child shows improvement in the intervention phase. As a result, child 3 and child 4 start their intervention phase much later. To avoid any bias due to the extended baseline phase, intermittent probes or limited sessions were carried out.

The intervention phase lasted for 20 sessions for each child. Each intervention phase session consisted of 10 minutes of

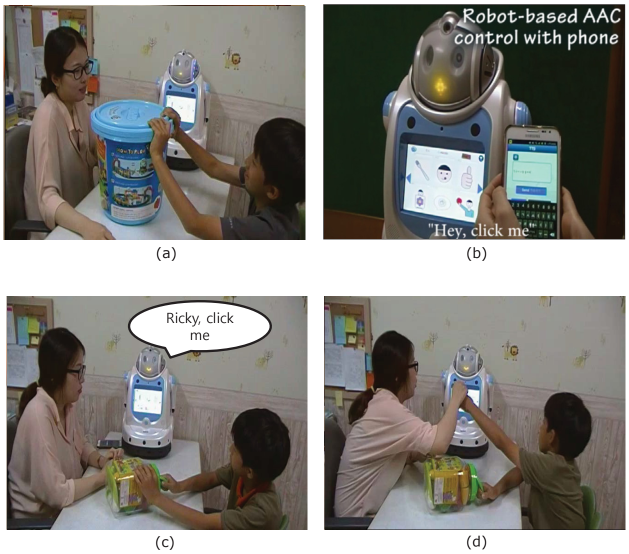

Figure 3. (a) The child wants to open a packaged toy and the therapist is waiting for the child's response. (b) Phone application to let the robot tell the child. (c) The robot is calling the child. (d) Therapist is showing how to use the AAC by taking the child's hand.

evaluation (which duration is identical to that of the baseline phase with no intervention) and 20 minutes of intervention. The evaluation portion is necessary to measure the impact of intervention from the previous session on the child.

The intervention process consisted of the following steps.

(a) Wait: After the therapist creates a communicative situation (e.g., there is a packaged toy on the table and the child needs the therapist's help to open it (Figure 3(a))), the therapist waits 5 seconds for the child's response. Other examples of intervention strategies are described in Table 2).
(b) Induce & Model : If the child does not respond for 5 seconds, the therapist induces child's response with the robot. For example, the robot tells the child "Bob, Click me!" as the robot can be controlled through the smartphone by the therapist (Figure 3(b)(c)). In addition, the therapist shows the child how to use the AAC by taking the child's hand and touching the intended symbol on the screen (Figure 3(d)).
(c) Response : If the child does not respond properly, the therapist demonstrates again. If the child responds properly or shows attempts to respond, the therapist then responds accordingly and encourages the child.

For example, for a game activity with trains, the intervention strategy would be for the therapist to ask the child "Do you want this toy?"; the goal is to encourage the child to express the word train or to leverage the robot-AAC.

Maintenance phase – To ensure that the participants maintained their improvement, maintenance phase evaluation was performed 1 (child 1), 3 (child 2, child 3) and 4 (child 4) weeks after intervention stopped for each child. The evaluation during the maintenance phase was exactly the same as that during the baseline phase – i.e., robot-AAC was available but no intervention was provided.

Our initial goal was to improve the number of communication expressions using AAC. Since children with communication

Communication Function	Intervention Strategy	Target Behavior (AAC word)
Activity Request	Create a situation in which the child needs therapist's help and the therapist pays attention to other things	Open please Unpack please
Object Request	Leave objects in visible but unreachable location	Knife please Spoon please
	Therapist is playing with a toy and says to the child. "Do you want this toy?"	Bubbles Toy please Train please
Reject	Create a situation the child does not like	I don't want it Don't do it
Naming	Show the object. If the child does not respond, therapist will ask "What is this?"	Carrot Plate Pig Water Bubbles
Attribute	When eating food, ask the child "How is it?"	Delicious
	When the child is laughing, ask the child "how do you feel?"	Funny
	Therapist asks the child "how is that?"	Pretty
Argument	When the child is playing with a toy, therapist pretends to take it.	I want to do it It's mine

Table 2. Different intervention strategies used in the study.

disorders have not developed sufficient speech to communicate well, they often communicate through other methods, including vocalization and gestures. As a result, increased communication expression through AAC can affect other methods of communicative expression, since AAC is a method of practicing communicating with other people. In this study, we measured the following characteristics of the children in order to measure their language development.

AAC : The AAC symbol is used to touch and point at symbols to indicate communication intent using the robot-based AAC application.

Gestures : Actions performed with the intent to communicate. Gestures in this study involve the use of fingers, hands, head, and limbs (e.g. waving, pointing, head nods/shakes, hand reaching), facial features (e.g. blowing), or total body movements (e.g. body shakes).

Vocalization : Vocalization included unintelligible speech word utterances that corresponded with the target word (e.g. "tra" for train) and any sound uttered with the intent to communicate (e.g. "wow" to express joy).

Speech : Speech included word utterances and word approximations. A word utterance was defined as the child clearly saying the name of the item or activity during playing. A word approximation was defined as the child making any vocalizations that did not exactly match the name of the mentioned item or activity but included at least one consonant and one vowel (e.g. "trai" for train).

Sessions for all children were video recorded and the coding and processing of the video were performed by two researchers in order to quantify the AAC, gestures, vocalizations, and speech metrics. The expressions were counted only when the child communicated with the therapist. Inter-observer Reliability [18] was calculated to ensure that the counted values were reliable because determining non-AAC communication attempts (e.g., gestures, speech and vocalization) could be subjective according to the analyse of individual therapists.

Inter-observer Reliability – The interventionist and a second assessor (major in speech language pathology; has experimented in interventions with pre-schoolers with difficulties in language acquisition) independently recorded target behaviors from the video for 100% of opportunities. Inter-observer reliability was calculated on the basis of the following formula.

$$\text{Inter-observer Reliability}(\%) = \frac{\min(\text{observer1}, \text{observer2})}{\max(\text{observer1}, \text{observer2})} \times 100$$

where observer1 and observer2 are the expression values measured by the interventionist (i.e., therapist) and the second assessor, respectively. Overall reliability ranged from 90.4% to 100% across sessions.

Based on the data collected during the three phases, the following analyses were performed.

Data Analysis – Line graphs pertaining to the dependent variables were analyzed to determine the "magnitude of change index," or the "effect size", called the Improvement Rate Difference (IRD [21]). IRD is the difference or change in the percent of high scores from the baseline to the intervention phase. IRD was calculated using the following formula.

IRD = Intervention improvement Rate - Baseline improvement Rate

The Intervention improvement Rate is defined as the number of sessions in the intervention phase that had an expression value that was larger than the *maximum* expression value in the baseline phase, divided by the total number of intervention sessions. The Baseline improvement Rate is defined as the number of sessions in the baseline phase that had an expression value that was larger than the first session in the intervention phase, divided by the total number of baseline sessions.

For example, if the baseline has 16% high scores, and the intervention phase has 83% high scores, IRD will be .83-.16 = .67. The IRD has a maximum value of 1.00 (no data-overlap between phases), and a chance-level of .50. IRD of approximately .50 or lower indicates small or questionable effect; IRD scores between approximately .50 and .70 are considered to show moderate effects; IRD scores of approximately .70 or .75 or higher are considered to show large or very large effects [21].

RESULTS

The results of the study are shown in Figure 4 and Table 3. For Figure 4, the x-axis shows the different sessions; the y-axis represents the frequency of communication expressions. The data is summarized in Table 3.

The sessions were carried out three times a week (Mon, Wed, Fri); the sessions with the four children were done during the same 6-month time period; however, each child had individual sessions with a therapist. Data points are connected with a line only if the data were collected from consecutive sessions. For example, the multiple-probe design used resulted in some of the children not attending all of the sessions during the baseline phase.

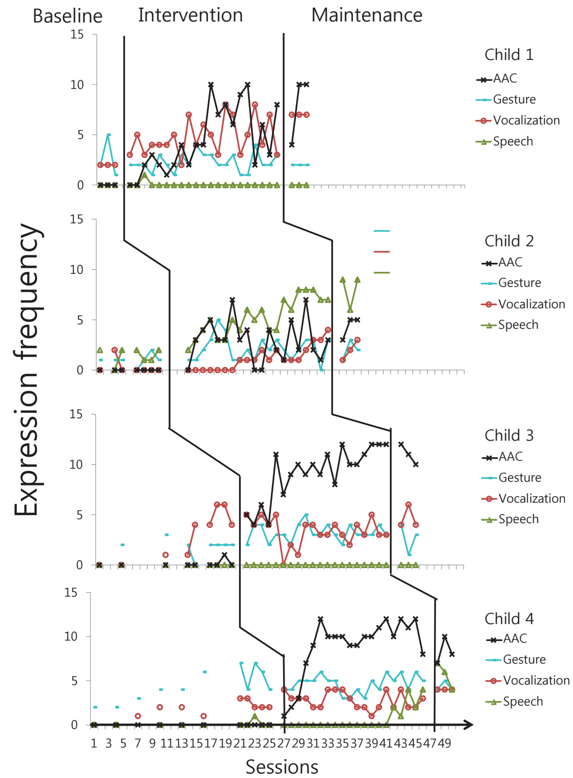

Figure 4. Frequency of communication expressions in our study for the 4 children in the study. The results are shown for all three phases: baseline, intervention, and maintenance.

Child 1 mostly communicated using gestures during the baseline phase. After the intervention phase, the use of gestures slightly decreased but communication using vocalization and AAC increased. In general, the child at the initiation of intervention participated in communicative situations using AAC as well as vocalization. From the 8th intervention, communicative expression via AAC and vocalization were observed to be in opposition to each other. In particular, when AAC expression indicated high frequency, vocalization had low frequency compared with AAC expression. Therefore, AAC expression is in sharp contrast with that of vocalization on the graph. The IRD (comparing the baseline phases to the intervention phase) was .95 for vocalization and .90 for AAC; this indicates that the intervention had a large effect. In contrast, the intervention had no effect on speech or gestures.

Child 2 demonstrated no use of AAC during the baseline phase; this child communicated using gestures, vocalization, and limited speech. After the intervention, child 2 mainly communicated via speech and AAC. In comparison to the baseline phase, gestures and vocalization slightly increased. At the initiation of the intervention, communicative expression using AAC was coincidentally found to increase with speech expression. From the 8th intervention, speech expression indicated a higher frequency compared with that of AAC expression. The IRD (comparing the baseline phases to the intervention phase) was speech (.95), AAC (.85), and gestures (.81); this indicates that the intervention also had a large impact on child 2.

	Pattern	Baseline (Std. dev)	Intervention (Std. dev)	Effect size (IRD)	Mainte-nance (Std. dev)
Child 1	AAC	0	4.25 (3.1)	0.9	8 (2.8)
	Gesture	2.66 (1.7)	2.25 (0.9)	-0.33	2 (0)
	Vocalization	2 (0)	4.85 (1.7)	0.95	7 (0)
	Speech	0	0.05 (0.2)	0.05	0
Child 2	AAC	0	2.95 (2.01)	0.85	4.33 (0.94)
	Gesture	1 (0.53)	2.15 (1.19)	0.81	2 (0.82)
	Vocalization	0.29 (0.7)	1.15 (1.15)	0.01	2 (0.82)
	Speech	1.43 (0.73)	5.25 (1.81)	0.95	8 (1.41)
Child 3	AAC	0.11 (0.31)	9.1 (2.57)	0.89	11 (0.82)
	Gesture	1.67 (0.94)	3.2 (0.81)	0.25	2.67 (1.25)
	Vocalization	2.89 (2.28)	3.35 (1.31)	-0.22	4.67 (0.94)
	Speech	0	0	0	0
Child 4	AAC	0	8.9 (3.19)	1	8.33 (1.25)
	Gesture	4.45 (1.72)	4.65 (0.96)	-0.18	4.33 (0.47)
	Vocalization	1.63 (0.98)	2.8 (0.93)	0.03	4 (0)
	Speech	0.1 (0.3)	0.65 (1.28)	0.16	5.66 (1.25)

Table 3. Results of the study that include the average of the different expressions, their standard deviation and their effect size.

Child 3 mostly communicated using gestures and vocalization during the baseline phase. After the intervention phase, child 3 mainly communicated using AAC. Use of gestures and vocalization slightly increased in comparison to those during the baseline phase. Initially, at the start of the intervention, vocalization expression gradually decreased compared to AAC expression improvement. From the 3rd intervention, AAC expression continually maintained a high frequency compared with that of vocalization. The IRD (comparing the baseline phases to the intervention phase) was AAC (.89), which indicates that the intervention had a large effect.

Child 4 demonstrated no use of AAC or speech during the baseline phase; this child mostly communicated using gestures and vocalization. After the intervention, child 4 mainly used communicative expression via AAC. Compared with the baseline phase, expression using gestures was incredibly similar. However, in the baseline, the use of vocalization and speech slightly increased compared with that of communicative expression. In general, vocalization expression at the initiation of intervention gradually decreased compared to AAC expression. From the 4th intervention, AAC expression continually maintained a higher frequency than that of vocalization. The IRD was AAC (1.00), which indicates that the intervention had a significant effect. By contrast, there was no effect on speech, vocalization, or gestures.

Although the frequencies of communicative expression were different among all the children, all four children demonstrated an effect size of more than .80 on AAC. Some of the other methods were also found to lead to improvement for child 1 in terms of Vocalization (.95) and for child 2 in terms of Gesture (.81) and Speech (.95). Even though there was no communication improvement for child 3 or child 4, except for AAC, these children communicated much more with AAC than they had before. Using AAC can affect social interactions/communication skills positively [5, 19]. As a result, the influence of AAC intervention using humanoid robots was shown for all the participating children. In addition, the improved frequency was mostly maintained during the maintenance phase, during which there was no intervention; this illustrates the positive impact of robot-based AAC on the communication skills of nonverbal children with communication disorders.

Observations: Robots have been used in many research projects, including research on autism [4, 7, 9, 17, 20]. Robots have appearances similar to that of humans and can be more psychologically friendly than can other devices or systems [2, 3, 12]. As a result, children with autism who are weak at communicating with people tend to like robots. In our study, we observed the actions and behaviors of participants, which showed that they were clearly very interested in the robots and that they were enjoying the therapy sessions: the children were engaged in touching the robots as soon as they came into the room, they looked closely at the robots' facial expressions and mouths, pulled on the robots' arms, and laughed seeing the robots.

LIMITATIONS AND FUTURE WORK

Compared to other HCI research studies, the number of participants was low but other studies involving special-needs participants often have small numbers of participants because of the difficulty of recruiting participants and the length of study that is necessary. Additional participants could have possibly shown different outcomes, e.g., robot-based AAC might not have been as effective for some participants. However, for each of the participants in this study, our results showed improvement in communication skills through intervention. We did not pursue a direct comparison of robot-based AAC with any alternative AAC (such as tablet-based AAC). However, as described earlier, a single form of AAC is not necessarily effective across a range of participants, especially in children, and the focus of this work was to evaluate the effectiveness of robot-based AAC.

Through our study, we found that the participants were interested in the various reactions of the humanoid robot. In this study, we only used voice and a few reactions (facial expressions and mouth shape) of the iRobi robot. However, in addition to simply moving its head, arms, and wheels, the iRobi can perform additional movements, including various dances. As part of our future work, it remains to be seen what impact these additions to the AAC program will have on increasing the attention of participants and possibly further improving their communication skills. It also remains to be seen if robot-based AAC can be leveraged to expand the vocabulary of the non-verbal children.

SUMMARY

Augmentative and Alternative Communication (AAC) is an important method to improve communication for nonverbal children. In this study, we have showed how robot-based AAC can be an effective method of improving the communication skills of nonverbal children; our results show robot-based AAC to be a promising alternative form of AAC for nonverbal children with communication disorders.

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