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Vocal Production of Young Children with Disabilities During Child-Robot Interactions

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KEY WORDS

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ABSTRACT

The effects of a socially interactive robot on the vocalization production of five children with disabilities (4 with autism, 1 with a sensory processing disorder) were the focus of the intervention study described in this research report. The interventions with each child were conducted over 4 or 5 days in the children's homes and involved investigator-facilitated robot-produced speech and movements to engage the children in child-robot and child-mother interactions. Results showed that for the children as a group and for 4 of 5 children individually, the children's vocalization production increased from a nonintervention, baseline condition to the intervention phases of the study. The utility of socially interactive robots for intervening with young children with disabilities is described.

Socially interactive robots are hypothesized to have behavioral-enhancing effects on young children with disabilities (e.g., Boser et al., 2011; Iacono, Lehmann, Marti, Robins, & Dautenhahn, 2011), including their social, communication, and language development (e.g., Costa et al., 2011; Robins, Dautenhahn, & Dickerson, 2009, February). Reviews of available evidence, however, indicate that few studies have included empirical tests of whether socially interactive robots in fact function as social agents (Diehl, Schmitt, Villano, & Crowell, 2012; Dunst, Prior, Trivette, & Hamby, 2013). One exception is a study by Kim et al. (2013) who found that embedding a social robot into child-robot-adult interactions influenced children's verbal production. As noted by the investigators, the "study provides the largest demonstration of social human-robot interaction in children with autism to date" (Kim et al., 2013, p. 1038).

As part of a line of research on the utility of socially interactive robots for intervening with young children with disabilities (Dunst, Prior, & Trivette, 2012; Dunst, Trivette, Prior, Hamby, & Embler, 2013a, 2013b), we conducted two studies of 11 children with autism, Down syndrome, and attention deficit disorders where the effects of a socially interactive robot on the children's vocalization production was the focus of investigation (Dunst, Trivette, Prior, Derryberry, & Hamby, 2013). Popchilla (Interbots, 2011), a chinchilla-looking robot, was used during intervention sessions with each child and his or her mother to engage the children in child-robot and child-mother interactions (see Dunst, Prior, Hamby, & Trivette, 2013). The socially interactive robot was remotely controlled by a practitioner who used programmable speech and robot arm, ears, mouth, and eye movements to engage the children in social interactions. The children's vocalization production during both the baseline and intervention phases of the studies were digitally recorded using the Language ENvironment Analysis (LENA) system (Xu, Yapanel, & Gray, 2009). LENA software includes speech-identification capabilities that permit separation of child vocalizations from all other speech and other sounds that are produced within the immediate environment.

The results from the two studies showed, in general, that the socially interactive robot did not increase the majority of the children's vocalization production. Pop-

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chilla had vocalization suppression effects with four children, no effects with four children, and vocalization enhancement effects with only three children. There were, however, several methodological factors that may have accounted for the study results. Data collection during both the baseline and intervention phases of the studies were obtained during single sessions, where the baseline conditions lasted only 4 to 6 minutes and the intervention sessions lasted only 10 to 15 minutes. According to Scassellati et al. (2012), data collected on only one occasion for only a short period of time may not provide an adequate test of the effects of socially interactive robots on children's behavior. Additionally, the suppression effects found for a number of children may have been due to the novelty of Popchilla and its capabilities rather than a lack of effect by the robot. Studies of the effects of novel objects or events on young children's behavior have found exposing children to novelty often decreases child behavior engagement following the introduction of novel objects or events (e.g., Bornstein, 1985). The possibility that these factors may explain the results in our previous studies (Dunst, Trivette, Prior, Derryberry et al., 2013) were taken into consideration in the investigation described in this research report by extending the duration of the baseline and intervention sessions and by conducting the study over a 4- or 5-day period of time with each child.

METHOD

Participants

The participants were five children ranging in age from 18 to 59 months (Mean = 42, SD = 16). The children's developmental ages ranged between 15 and 43 months (Mean = 26, SD = 10). Four of the children were diagnosed with autism and one child was diagnosed with a sensory processing and attention deficit disorder. Two of the children with autism had severe symptoms of autism spectrum disorders and two children with autism had mild-to-moderate symptoms of autism spectrum disorders (Schopler, Van Bourgondien, Wellman, & Love, 2010). Three of the children were male and two of the children were female.

Procedure

A multiple baseline design across children (Barlow, Nock, & Hersen, 2009) was used to conduct the study and collect the child vocalization data. The research design included a baseline, nonintervention condition and 4 or 5 intervention sessions for each child which occurred on separate days. The baseline and intervention sessions each lasted between 15 and 25 minutes with each child. Data from the first 15 minutes of both the baseline and each intervention session were the focus of analysis reported in this paper.

The baseline condition involved child vocalization recordings where Popchilla was available to each child but where the social robot produced no speech or movements. Each of the intervention sessions involved investigator-facilitated robot interactions using professionally recorded speech by a child actor together with robot arm, ear, mouth, and eye movements. The particular sounds, words, phrases, songs, rhymes, and other speech used during the intervention sessions are listed in Appendix A. The sounds and speech that were recorded for use in the study were selected in order to have behavior-engaging features and included phrases that would elicit or evoke child vocalizations and language (see Dunst, Prior, Hamby et al., 2013).

Child Vocalizations

Continuous recordings of child vocalizations were made using LENA digital language processing devices during the baseline and intervention phases of the study (Xu et al., 2009). The recorders fit into a small pocket of a vest worn by a child. The recorder digitizes all sounds and language produced in the environment and transfers the audio data to a laptop computer for subsequent analysis using the LENA language environment software package.

The LENA software includes speech-identification capabilities that permit separation of all sounds and language recorded during a session into adult male and adult female speech, target child speech, the speech of other children if present, noise, television or radio, etc. The three main types of data that were collected as part of the study were child vocalizations, adult (parent) words, and conversational turns (LENA Foundation, 2013). Child vocalizations were the focus of analysis reported in this paper which included normal sounds distinct from cries, vegetative sounds, and other fixed signals.

Data Analysis

The child vocalization data from the study were analyzed in a number of ways to assess whether child-robot interactions had the effect of increasing the number of vocalizations produced by the children. We first computed for each child the total number of vocalizations during the first 15 minutes of baseline recordings and for each 15-minute block (days) of the intervention sessions. These data were used to calculate group means and standard deviations in order to compute Cohen's *d* effect sizes for baseline vs. intervention phase differences for the children as a group. Second, we computed Cohen's

d effect sizes for each child for baseline vs. intervention phase differences to ascertain if the effects of child-robot interactions on child vocalizations were similar or different. Cohen's *d* effect sizes were computed as the differences in the mean scores for the baseline vs. an intervention phase divided by the pooled standard deviation for the two conditions (Dunst & Hamby, 2012).

RESULTS

The average number of child vocalizations for the five children was 56.60 (SD = 60.20) during the baseline condition and 72.08 (SD = 37.64) for all intervention sessions combined. The Cohen's *d* effect size for the between baseline vs. all intervention sessions combined comparison was 0.31. This result showed that Popchilla had a small but discernible effect on increasing the children's production of vocalizations.

Figure 1 shows the average number of vocalization productions for the five children as a group for the baseline and each of the five intervention phases of the study. The effect sizes for the baseline vs. individual intervention sessions were 0.13, 0.22, 0.71, -.08, and 0.69 respectively. These results indicate that Popchilla had small to medium effects on increasing the children's vocalization production during 3 of the 5 intervention sessions (I-2, I-3, and I-5).

The effect sizes for the baseline vs. individual intervention phases of the study for each of the children are shown in Figure 2. Popchilla had positive effects on vocalization production for two children (Betty and Carson) during 3 of the 5 intervention sessions and vocalization production enhancement effects during 4 of the 5 intervention sessions with two children (Dotie and Evan). The social robot had vocalization production suppression effects for one child during all five intervention sessions (Andrew).

DISCUSSION

The results from our study indicated that Popchilla was effective for enhancing the vocalizations of young children with disabilities as part of interventions designed to improve the children's social-communication interaction skills. In the study reported in this paper, the socially interactive robot was used to engage the children in child-robot and child-mother interactions in a manner that focused on joint attention and reciprocity designed to enhance the children's communication and language abilities (e.g., Capirci, Montanari, & Volterra, 1998; Ma, Golinkoff, Houston, & Hirsh-Pasek, 2011; Saxon & Reilly, 1998). The results showed that the robot proved to be a useful tool as the part of the interventions with the children.

The findings provide support for the contention of Scassellati et al. (2012) that interventions of short duration may not be adequate for demonstrating the effects of social robots on children's social behavior. In our two previous studies of children's vocalization production as part of child-robot interventions which were conducted in only one session (Dunst, Trivette, Prior, Derryberry et al., 2013), we found that Popchilla had positive effects on the vocalizations of only 3 of 11 children (27%). In contrast, in the study described in this research report, where the interventions were conducted over 4 or 5 days, Popchilla had positive effects on 3 of the 4 children (75%).

Young children with disabilities often demonstrate delays in their vocalization and language development (Buschbacher & Fox, 2003; McCathren, Yoder, & Warren, 1999; Mundy, Kasari, Sigman, & Ruskin, 1995).

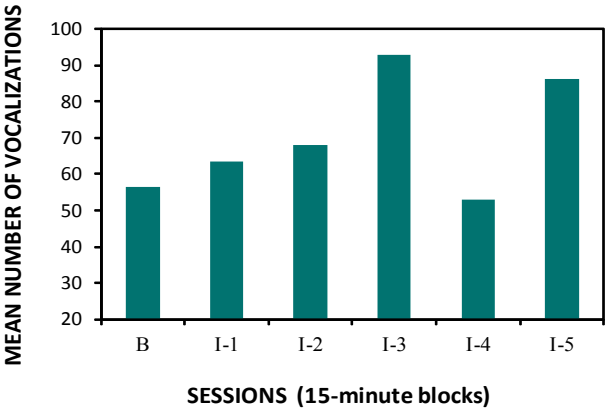

Figure 1. **Mean number of child vocalizations during the baseline (B) and five intervention (I) sessions (days).**

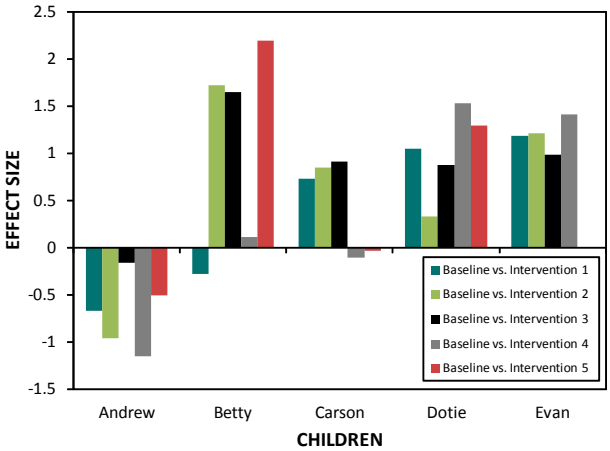

Figure 2. **Cohen's *d* effect sizes for the differences in child vocalization production for the baseline vs. each of the five 15-minute blocks (days) of intervention. (NOTE. The children's names are fictitious to protect their identities.)**

Contingent responsiveness to the children's attempts to communicate as well as their vocalizations has been found to be effective for improving these child behaviors (Dunst, Gorman, & Hamby, 2010). Observations and both parent and investigator reports suggested that Popchilla functioned as a reinforcer for the children's behavior which may have been one factor that explains the increases in the children's vocalizations.

Another factor that might explain the positive effects on the children's vocalizations is the particular speech that was professionally recorded for our Popchilla intervention studies (Dunst, Prior, Hamby et al., 2013). The speech included phrases and both songs and rhymes that were used to engage the children in social interactions with both the robot and the children's mothers. Consequently, the robot speech used as part of the interventions may have played a role in increasing the children's vocalization production.

Although socially interactive robots are being touted as useful tools for intervention with young children with disabilities (e.g., Dautenhahn & Werry, 2004; Kozima, Michalowski, & Nakagawa, 2009; Kozima & Nakagawa, 2006), reviews and syntheses of studies of socially interactive robots with young children suggest that most studies are methodologically flawed or do not include direct tests of the influences of robots on children's behavior (Diehl et al., 2012; Dunst, Prior, Trivette et al., 2013). Studies like that described in this research report are needed to establish the effectiveness robot-mediated interventions for improving the social behavior of young children with disabilities.

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Appendix A

Professionally Recorded Sounds and Speech Used in the Vocalization Production Study

Sounds and Words[a]	Phrases	Songs and Rhymes[b]
Ears	All done	ABC Song
Eyes	Can you do this?	A Peanut Sat
Foot	Can you do this? (raises left arm)	Do you want me to sing more?
Great!	Can you do this? (raises right arm)	Down By the Bay
Ha, ha, ha (laughing)	Can you do this? (raises both arms)	Hooorrrayyy!!!! (music and dance)
Hi	Can you do it again?	If You're Happy and You Know It
Mmmmm	Can you give it to mommy?	Itsy Bitsy Spider
Mouth	Can you give it to daddy?	Mother Goony Bird
Ouch	Can you move your head?	Old McDonald
Songs	Can you put the hat on?	Twink-A-Link
Tail	Can you shake your arms?	Wheels on the Bus
Tummy	Can you show mommy a happy face?	
Wheee...wheee!	Dance with me	
Yay	Do you want to play?	
Yeh, yeh	Do you want to sing?	
Andrew	Give some to mommy/daddy	
Betty	Give the ball to daddy	
Carson	Give the ball to mommy	
Dotie	Give the book to daddy	
Evan	Give the book to mommy	
	Give the doggy to daddy	
	Give the doggy to mommy	
	Give the hat to your daddy	
	Give the hat to your mommy	
	Give the truck to daddy	
	Give the truck to mommy	
	Good bye	
	How are you?	
	I am happy	
	I am hungry, feed me	
	I don't like that	
	(If correct) Yay, you did it	
	(If wrong) Try again	
	I see something green, show me something green	
	Let's play	
	Let's stop for today	
	Look at the block	

Appendix A, continued.

Sounds and Words[a]	Phrases	Songs and Rhymes[b]
	Look at the book	
	Look at the doggy	
	Look at the truck	
	My name is Popchilla	
	Mmmmm, yummy, I like that	
	Now you try, we will follow you	
	Point to _____	
	Point to my nose	
	Popchilla is getting tired	
	Roll me the ball	
	Roll the truck to me	
	See you later	
	Show daddy	
	Show me the book	
	Show me the doggy	
	Show me where the ball is	
	Show mommy	
	Sing with me	
	Touch my _____	
	That was fun!	
	What is your name?	
	Where is my hat?	
	Where is your daddy?	
	Where is your mommy?	
	Where is your nose	
	Who is that?	
	Wow, wow, wow	
	You did it!	
	You did it! You did it!	
	You eat some	
	You try	

[a] The children's names listed below are fictitious to protect their identities.

[b] The lyrics for each of the songs and rhymes were part of the software used to engage the children in child-robot interactions.