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Effects of Child-Robot Interactions on the Vocalization Production of Young Children with Disabilities

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KEY WORDS

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Popchilla
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Language ENvironment Analysis
LENA
Intervention
Autism spectrum disorder
Down syndrome
Attention deficit disorder

ABSTRACT

Findings from two studies investigating the effects of a socially interactive robot on the vocalization production of young children with disabilities are reported. The two studies included seven children with autism, two children with Down syndrome, and two children with attention deficit disorders. The Language ENvironment Analysis (LENA) software package was used to continuously record child vocalizations during both baseline and intervention phases of the studies. Results showed that child-robot interactions were differentially effective in increasing the children's vocalization production. Several reasons are offered for the fact that child-robot interactions did not have vocalization production effects for a number of the children.

The purposes of the two studies described in this research report were to determine if child-robot interactions had vocalization production effects on young children with identified disabilities. The robot used in the studies was Popchilla, a toy-like robot that is controlled by a practitioner or parent to engage children in child-robot interactions. Figure 1 shows a picture of the chinchilla-looking creature. Popchilla has moveable arms, ears, mouth, and eyes (controlled by a practitioner or parent) and programmable speech output that is part of the software package (Interbots, 2013) for using the robot as part of interventions to promote the social-affective and social interactive behavior of young children with disabilities (e.g., Feil-Seifer & Mataric, 2008; Miyamoto, Lee, & Okada, 2007). This particular socially interactive robot was used in the studies described in this research report based on findings from several studies which indicated that parents preferred Popchilla as part of the interventions with their young children with disabilities (Dunst, Trivette, Prior, & Hamby, 2013b; Dunst, Trivette, Prior, Hamby, & Embler, 2013c).

Socially interactive robots are hypothesized to be nonthreatening and novel mechanical devices that can be used to engage young children with disabilities in social exchanges to improve their interactional skills, joint attention, language development, and other social-communicative competencies (Boser et al., 2011; Kozima & Nakagawa, 2006; Robins, Dickerson, Stribling, & Dautenhahn, 2004; Scassellati et al., 2006). There is evidence from studies in developmental psychology that novel objects and events, and the people and things that young children find situationally interesting, are associated with better social and language outcomes (e.g., Pruden, Hirsh-Pasek, Golinkoff, & Hennon, 2006; Silven, 2001). Research syntheses of findings from these kinds of studies indicate that novelty and the interestingness of people, objects, and events have social-communication enhancing consequences (Dunst, Jones, Johnson, Raab, & Hamby, 2011; Dunst, Trivette, & Hamby, 2012a, 2012b; Dunst et al., 2013b; Raab, Dunst, & Hamby, 2013). An extensive review of child-robot studies focusing specifically on children with disabilities between 1 and 6 years of age, however, found very few studies that

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employed research designs that permitted direct tests of the effects of child-robot interactions on children's social-communication abilities or included child outcome measures for testing the hypothesized relationships between child-robot interactions and child social behavior (Dunst, Prior, Trivette, & Hamby, 2013). One exception is a study by Kim et al. (2013) who found that a social robot had positive effects on the language production of young children with autism.

The effects of Popchilla on the vocal production of young children with disabilities reported in this paper were examined by employing a multiple baseline design (Barlow, Nock, & Hersen, 2009) and by using the Language ENvironment Analysis (LENA) system for digitally recording child vocalization production during nonintervention and intervention conditions in each of the studies (Richards, Gilkerson, Paul, & Xu, 2008; Xu, Yapanel, & Gray, 2009). The research design permitted the analysis of child vocalization production in a number of different ways, and LENA permitted the systematic collection of child vocalizations in exactly the same manner with each child. LENA has been used to evaluate the effects of different kinds of interventions (e.g., Trask, 2012; Weil & Middleton, 2010) and to monitor similarities and differences in the language production of children with and without disabilities (e.g., Oller et al., 2010; Warren et al., 2010).

METHOD

Participants

The participants in the two studies were seven children with autism, two children with Down syndrome, two children with attention deficit and sensory processing disorders, and their mothers. The characteristics of the children in the two studies are shown in Table 1. Nine of the children were male and two were female. The children ranged between 37 and 80 months of age in Study 1 and between 18 and 54 months of age in Study 2. The children's mental ages ranged between 21 and 75 months in Study 1 and between 19 and 36 months in Study 2. The interventions were all conducted in the children's homes.

The *Childhood Autism Rating Scale* was completed on all 11 children (Schopler, Van Bourgondien, Wellman, & Love, 2010). Three of the children with autism had scores indicative of severe symptoms of autism spectrum disorders, three children had scores indicative of mild-to-moderate symptoms of autism spectrum disorders, and one child had a score indicative of borderline symptoms of autism spectrum disorders. None of the four children with either Down syndrome or attention deficit disorders had scores indicative of autism spectrum disorders.

***Figure 1.* The toy-like social robot that was used in the studies of the effects of a socially interactive robot on child vocalization production.**

Procedure

The vocalization production of each child was recorded during a baseline, nonintervention phase in each study, where Popchilla was available to each child but remained stationary and during an intervention phase where the robot was used to engage each child in child-robot and child-robot-parent interactions. The baseline conditions in Study 1 lasted between 5 and 6 minutes and between 5 and 11 minutes in Study 2. The intervention phases in Study 1 lasted between 10 and 16 minutes in Study 1 and between 22 and 27 minutes in Study 2.

The child-robot interventions in Study 1 involved investigator-facilitated robot interactions with each child, using the programmable speech included as part of the robot software package with arm, ear, mouth, and eye movements accompanying the speech. The particular words, songs, phrases, and other types of speech available to the investigators during the intervention phase of Study 1 are included in Appendix A. The particular speech used with each child was individualized based on observations prior to the study and reports of each child's preferences by the children's parents.

Observations during and feedback from both the research staff and parents in Study 1 indicated that the clarity of speech was often unintelligible and proved to be confusing to some children. We also found that the use of the programmable speech, to a large degree, did not have characteristics that would likely promote child joint attention or elicit child-initiated interactions. As a result, we had a professional child actor rerecord a subset of words, phrases, songs, and sounds used in Study 1 to improve clarity and intelligibility for use in Study 2 and

Table 1
Characteristics of the Children in the Two Child Vocalization Production Studies

		Age (months)[b]			Childhood Autism Rating Scale	
Child[a]	Gender	CA	MA	Child Diagnosis	Severity score	Level
Study 1						
Abe	Male	55	44	Autism	34	Mild/moderate
Bill	Male	37	26	Autism	36	Mild/moderate
Crystal	Female	48	21	Autism	41	Severe
Dale	Male	66	53	Autism	30	Mild/moderate
Earl	Male	39	36	Autism	28	Minimal/none
Frank	Male	80	75	Down syndrome	27	Minimal/none
Study 2						
George	Male	54	43	Autism	31	Mild/moderate
Henry	Male	29	35	Down syndrome	25	None
Ivan	Male	38	34	Attention deficit	16	None
Jolene	Female	18	22	Attention deficit	20	None
Kevin	Male	35	19	Autism	37	Severe

[a] All of the children's names are fictitious to protect their identities.
[b] CA = Chronological age and MA = Mental age.

added words and phrases that were more likely to promote child-robot and child-robot-adult interactions and enhance child engagement in joint attention episodes with the robot and each child's parent. The list of words, phrases, songs, and other speech used in Study 2 is included in Appendix B.

Child Vocalizations

Continuous recordings of child vocalizations were made using LENA digital language processing devices during the baseline and intervention phases of the studies (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 language and sounds 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 coded as part of the studies described in this paper 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 (LENA Foundation, 2013).

Data Analysis

The child vocalization data from both studies 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 5 minutes of baseline recordings and for each 5-minute block of intervention. These data were first used to compute group means and standard deviations in order to compute Cohen's *d* effect sizes for baseline vs. intervention phase differences for all children combined. 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

Study 1

Figure 2 shows the average number of child vocalizations per 5-minute block during the baseline and the

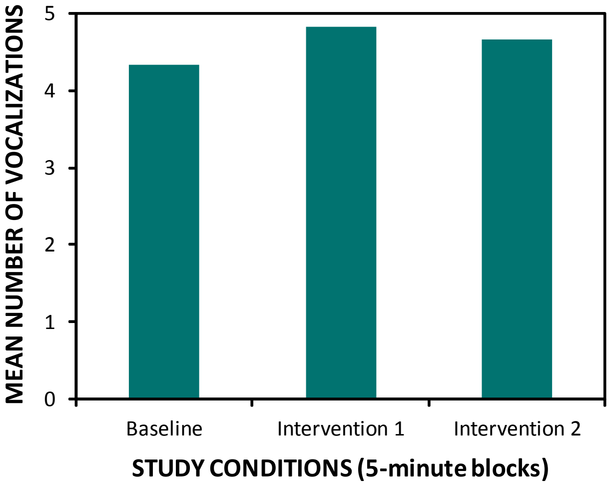

Figure 2. **Mean number of the children's vocalization production during the baseline and first 10 minutes of intervention in Study 1.**

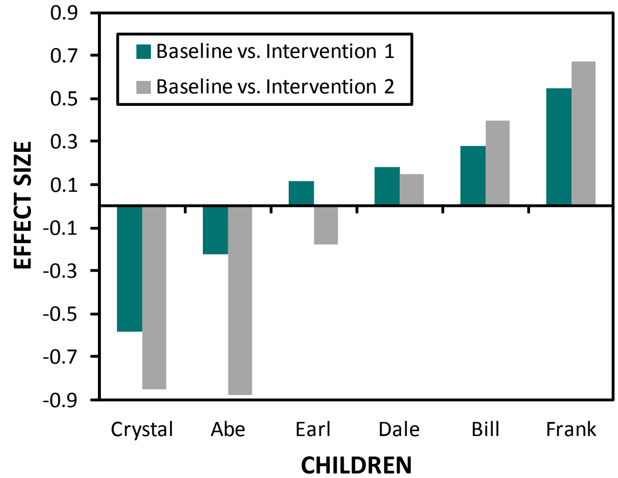

Figure 3. **Cohen's *d* effect sizes for the differences in child vocalization production for the baseline vs. two 5-minute blocks of interventions in Study 1.**

two intervention phases of the study. Several observations can be made from the results. First, vocalization production, on average, was very low. Second, there were no average effects of Popchilla on the children's vocalization productions. The Cohen's *d* effect size for Baseline vs. Intervention 1 phase difference was 0.14 and the effect size for Baseline vs. Intervention 2 phase difference was 0.08. The low levels of vocalization production may have been due, in part, to the fact that the children with autism in Study 1 tended to have higher autism spectrum disorder severity scores (see Table 1).

The extent to which the child-robot interventions may have influenced individual children's vocalization production was determined by effect size analyses of each child's dependent measures. The results are shown in Figure 3. Findings showed that Popchilla had vocalization suppression effects for two children (Crystal and Abe) and vocalization enhancement effects for two children (Bill and Frank). The effects of Popchilla on two children's (Earl and Dale) vocalization production were equivocal.

Study 2

The average child vocalization production for the five children in Study 2 is shown in Figure 4. There were increases in the children's vocalizations from the baseline to intervention phases of the study where the average number of vocalizations doubled and remained stable for the 15 minutes of child-robot interactions. The Cohen's *d* effect sizes for the baseline vs. the three intervention phases were 0.81, 0.49, and 0.61 respectively.

The effect sizes for the baseline vs. intervention phases of the study for individual children are shown in Figure 5. Popchilla had vocalization suppression effects for two children (Ivan and Jolene) and vocalization enhancement effects for two children (Henry, and George) during at least two 5-minute periods of the intervention phase of the study and no discernible effect for one child (Kevin).

DISCUSSION

Results from the two studies described in this report indicated that the effects of robot-child interactions on children's vocalization production differed child-by-child. Popchilla had positive effects on the vocalizations of only 2 of the 6 children in Study 1 and only 2 of the 5 children in Study 2. Among those children for whom child-robot interactions did not have positive effects, Popchilla had vocalizations suppression effects or no discernible positive or negative effects.

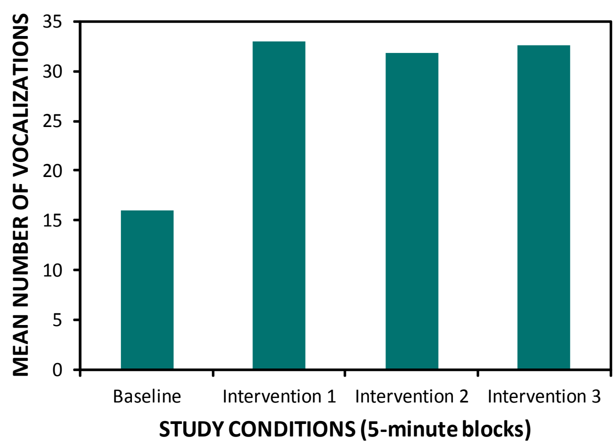

Figure 4. **Mean number of the children's vocalization production during the baseline and first 15 minutes of intervention in Study 2.**

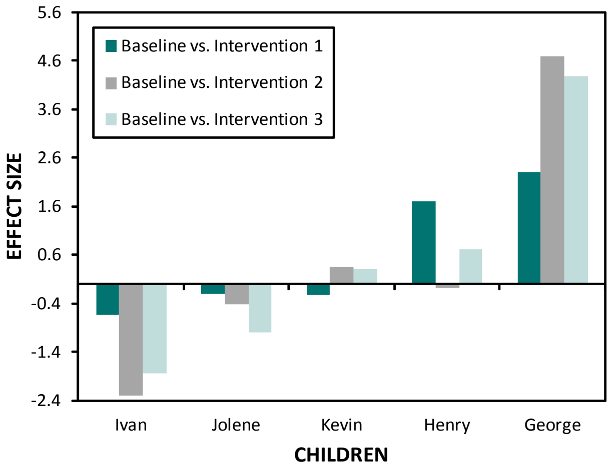

Figure 5. **Cohen's *d* effect sizes for the differences in child vocalization production for the baseline vs. three 5-minute blocks of interventions in Study 2.**

Children in Study 1, on average, produced very few vocalizations during either the baseline or intervention phases compared to the children in Study 2. Children in Study 2 produced, on average, four times as many vocalizations during the baseline condition compared to the children in Study 1 and 6 to 7 times as many vocalizations during the intervention phases of the study compared to the children in Study 1.

Several factors stand out as possible correlates of the differences in Studies 1 and 2. Children in Study 1 included mostly children with autism whose severity of autism spectrum disorders was more marked than those in Study 2. Another factor, at least in terms of the differences found during the intervention phase of the studies, is the fact that both the clarity and intelligibility of speech used in Study 2, and the interaction-facilitating language added to the programmable speech appeared to have influenced some of the children's vocalization production.

A third factor specifically noted by Scallallati et al. (2012) for the differential consequences of child-robot interventions on child social behavior is the fact that the two studies were conducted in a single session lasting only 15 to 20 minutes. Based on a review of social robot research studies of children with autism, these investigators noted that repeated child-robot interactive episodes distributed over sessions or days might provide better tests of the behavior-enhancing consequences of socially interactive robots. Findings from a study we subsequently conducted which included multiple intervention sessions as part of the investigation was used to determine if this methodological difference mattered in terms of the effects of Popchilla on children's vocalization production. This will be reported in a *Social Robots Research Report* that is in the process of being written.

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Appendix A

Popchilla World Software Speech Used in Study 1

Sounds and Words	Phrases	Songs and Rhymes[a]
Aaah!	Can you do what I say?	ABCs song
Again!	Clap your hands	BINGO was his name
Awww	Do what I do	Do your ears hang low?
Blpblpblpb	Don't like	Happy and you know it
Bye	Don't stop	Head, shoulders, knees and toes
Dance!	Feed me	Hokey pokey
Down	Follow me	Itsy bitsy spider
Ears	Good job	Mary had a little lamb
Eyes	Guess how I feel	Ring around the rosies
Foot	Hehehe, that tickles!	Twinkle twinkle little star
Gggah!	How are you today?	Would you like to hear a song?
Good	How do I feel?	
Goodbye	How do you feel?	
Gross!	I don't like that	
Ha, ha, ha (laughing)	I feel _____	
Head	I like that	
He, he, he	I'm hungry	
Hello	I'm Popchilla	
Hungry	I'm sorry	
Hi	I want _____	
La, la, la	Jump up and down	
Name?	Keep clapping	
No	Keep dancing	
Nomnomnom	Keep jumping	
Oooo	Keep sitting	
Ououu	Keep standing	
Pbfft	Let's be _____	
Please	Let's do it again	
Right	Let's make silly noises	
Sing	Let's play a game	
Sorry	Look at me	
Surprised	Look down	
Tail	Look left	
Tummy	Look right	
Uh oh!	Look up	
Up	One more time	

Appendix A, continued.

Sounds and Words	**Phrases**	**Songs and Rhymes**[a]
Wheee!	Please stop	
Yay	Raise your arm	
Yaaay!	Raise your left arm	
Yummy	Raise your right arm	
	Right arm	
	Right eye	
	Right foot	
	Sit down	
	Something blue	
	Something green	
	Something orange	
	Something purple	
	Something red	
	Something yellow	
	Stand up	
	Stomp your feet	
	Stop that	
	Thank you	
	That hurts	
	That's gross	
	That's my _____	
	That's silly	
	That was fun!	
	Touch my _____	
	You did great	
	You look _____	
	You're welcome	
	What's your name?	
	Will you feed me?	
	Will you pet me?	
	Will you scratch my ears?	
	Will you tickle my belly?	
	Would you like to hear a song?	

[a] The lyrics for each of the songs and rhymes are included as part of the software package.

Appendix B

Professionally Recorded Sounds and Speech Used in Study 2

Sounds and Words	Phrases	Songs and Rhymes[a]
Great!	Can you do this?	A Peanut Sat
Ha, ha, ha (laughing)	Can you do this? (raises left arm)	Do you want me to sing more?
Mmmmm	Can you do this? (raises right arm)	Down By the Bay
Wheee...wheee!	Can you do this? (raises both arms)	Hooorrrayyy!!!! (music and dance)
Yay	Can you do it again?	If You're Happy and You Know It
Yeh, yeh	Can you give it to mommy?	Itsy Bitsy Spider
	Can you give it to daddy?	Mother Goony Bird
	Can you move your head?	Twink-A-Link
	Can you put the hat on?	
	Can you shake your arms?	
	Can you show mommy a happy face?	
	Dance with me	
	Do you want to play?	
	Do you want to sing?	
	Give some to mommy/daddy	
	Give the ball to daddy	
	Give the ball to mommy	
	Give the book to daddy	
	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	

Appendix B, continued.

Sounds and Words	Phrases	Songs and Rhymes[a]
	Look at the block	
	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 my nose	
	Roll me the ball	
	Roll the truck to me	
	Show daddy	
	Show me the book	
	Show me the doggy	
	Show me where the ball is	
	Show mommy	
	Sing with me	
	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 lyrics for each of the songs and rhymes were included as part of the software used to engage the children in child-robot interactions.