A feasibility study of using Kaspar, a humanoid robot for speech and language therapy for children with learning disabilities*

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Abstract— **The research presented in this paper investigated if and how humanoid robots like Kaspar can be used as assistive tools in Speech, Language and Communication (SLC) therapy for children with learning disabilities. The study aimed to answer two research questions: RQ1. Can a humanoid robot be used to help children with learning disability to improve their speech, language and communication skills? RQ2. What is the measurable impact on children with learning disability and SLC needs interacting with a humanoid robot? A co-creation approach was followed, where professional guidance from experienced speech and language communication experts was sought, which then was used to inform the development of three therapeutic educational games. These were implemented on the Kaspar robot. Twenty children from two different special educational needs schools participated in the games in 9 sessions over a period of 3 weeks. Results showed significant improvement in participants' SLC skills – i.e. language comprehension, production and interaction skills – over the intervention. Findings of this research affirms feasibility, suggesting that this type of robotic interaction is the right path to follow to help the children improve their SLC skills.**

I. Introduction

Approximately 5 million people in the United Kingdom (UK), including 286,000 children have a learning disability [1]. It is estimated that 89% of the learning disabled population need speech and language therapy to help with their communication difficulties [2]. Whilst communication difficulties show a wide range and are different to every person, the following areas are commonly found to be of difficulty in the learning disabled population: (1) understanding speech, writing and symbols, (2) having a sufficient vocabulary to express a range of needs, emotions or ideas, (3) being able to construct a sentence, (4) maintaining focus and concentration in order to communicate, (5) fluency, (6) being able to articulate clearly which may be due to related physical factors, (7) social skills, a lack of which may prevent positive interactions with people [3]. The potentially extensive and long term effects of communication problems related to having a learning disability can have a very harmful effect on the people's health and social wellbeing if left without intervention [3]. If appropriate speech and language support is not available it may lead to mental health problems, as well as to reduced learning opportunities and participation in employment, which in turn may lead to isolation, challenging behaviour, risk of harm or abuse, and failure to reach potential in life [3]. Hence, speech and language therapy is absolutely crucial for children with learning disabilities. It promotes inclusive communication and accessible information for children with learning disabilities. It improves their quality of life, enabling them to build relationships and achieve their potential. Whilst a vast amount of research has investigated communication interventions and their impact on children with Speech Language and Communication Needs (SLCN), the possibility of using state of the art robotics technology, specifically focused on Speech Language and Communication (SLC) therapies has had very little investigation.

Research into the potential use of robotic technology for children began in the late 1990s, with Dautenhahn and Werry conducting some of the first studies in this area with Autism Spectrum Disorder (ASD) [4, 5]. Since then positive results in this domain have led to much more work being conducted into how robotic technology can be used as assistive tools for children with ASD [6]. Numerous reasons why social robots have an advantage include: their capacity to act as a playmate, their ability to display particular behaviours consistently and predictably and their ability to act as a social mediator. In addition, children often find robots less intimidating than humans because they may feel less judged by them [7]. Previous research investigating if humanoid robots could be used to interview children demonstrated that children are able and willing to interact with humanoid robots for information acquisition purposes, and that robots even provide advantages at interviewing children in challenging situations (e.g. interviews conducted by social services). [8, 9]. One of the particularly useful features of a robot that could be beneficial to SLC therapies is the capacity for consistent interaction that can be repeated for achieving sufficient exposure required for optimal learning. It is thought that children with SLCN can utilise implicit learning principles but with significant amount of input [10], which is possible via the robotic interaction. Based on literature suggesting that children with other disabilities respond well to social robots [7], it is likely that children with learning disabilities in need of SLC therapy could also benefit from robotic therapies via a series games that have purposeful goals [11]. To date, however, the work investigating the possibility of using robots to assist with speech and language is relatively limited. Some of previous research focused on children with conditions such as ASD

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[12], or hearing impairments [13], while others focused on the early acquisition of language with young children [14]. A more recent exploratory study [15] investigated the potential use of a social robot (NAO) in speech therapy intervention for children with language disorders. Their findings indicated that NAO had potential to increase motivation, and readiness towards learning as well as to improve attention span of children. Another pilot study, using the RASA robot in speech therapy sessions for children with language disorders found further supporting evidence for the potential usability of robots in SLC therapy with children [16]. These studies, however, both presented preliminary exploratory findings with small number of participants.

The study presented in this paper aimed to investigate further if and how humanoid robots can be used as assistive tools in SLC therapy for children with learning disabilities. It used the humanoid robot, Kaspar, originally developed in 2005 at the University of Hertfordshire for children with ASD [17]. Over the years, Kaspar has been used to work with more than 500 children in various settings [18], proven to be successful for a wide range of therapeutic and educational purposes both in schools and at homes, in addition to clinical settings [19, 20, 21, 22]. Recent case studies focusing on developing communicational skills in clinical settings of a children's hospital in Skopje, Macedonia with children with severe autism showed that sessions with Kaspar helped the children to learn basic social communication skills for the first time, and that these skills were then successfully generalised and used in their daily lives [23].

This current study investigated aimed to use Kaspar in Speech, Language and Communication (SLC) therapy for children with learning disabilities, investigating the following research questions (RQ):

RQ1. Can humanoid robots be used to help children with learning disability to improve their speech, language and communication skills?

RQ2. What is the measurable impact of interacting with a humanoid robot on children with learning disability and SLCN?

II. METHOD

This research was approved by the University of Hertfordshire's ethics committee for studies involving human participants, protocol number: aSPECS/SF/UH/04944(1). Informed consent was obtained in writing from all parents of the children participating in the study.

A. Participants

Twenty children from two different special education schools (a primary school and a secondary school) took part in the study after getting the written and signed consent of their parents or legal guardians. Their mean age was $M = 10.76$ ($SD = 2.43$) ranging from 6 to 14 years old. Three of them were female and 17 were male. Their diagnosis included Autistic Spectrum Disorder, Down Syndrome, Speech and Language Difficulties, Attention Deficit Hyperactivity Disorder and Global Developmental Delay.

B. Co-creation Method and Educational Targets analysis

Professional guidance from experienced speech and language communication experts was used to inform the development and testing of the therapeutic educational games that were developed for this study. Our partner special needs school provided information about the SLC objectives important to the education journey of the pupils. They also provided us with a breakdown of targets set against interactions with children at varying level of complexity. This included in a pool of exemplar targets for individual pupils (fully anonymised), featuring different objectives for various learning styles. This provided the co-creation input as a series of rows and columns of information per pupil.

TABLE I. Speech and Language development target classifications and the frequency of their occurrence.

SLC Target Classifications	
Code	**References**
Language production\Active or production verbs and derivative words	57
Language production\Production of phrases, grammatical structures or other objects	38
Bidirectional social interaction\Interaction partners	33
Games and activities	26
Language comprehension\Phrases or concepts to understand	24
Degree of independence\Use of aiding tools and toys	19
Degree of independence\Increasing independence	16
Bidirectional social interaction\Socially engaging verbs and derivative words	14
Desired success rate or frequency	14
Language comprehension\Comprehension verbs and derivative words	12
Language production\Production of phonemes or sound	11
Non-verbal communication	10

A frequency analysis was carried out in order to know which type of SLC targets were the most common in interacting with the children with special needs. The different phrases in the list were coded and classified into different categories related to SLC such as language comprehension, production or interaction. A second coder coded 20% of the targets and Cohen's Kappa was run to determine if there was agreement between the two coders on the classification of the phrases. There was a substantial agreement between the two coders ($\kappa = 0.75$).

As Table I demonstrates, the most common targets were related to language production and comprehension, the interaction between peers, and the engagement in activities and games.

C. Games

Three games were designed taking the above speech and language development targets into consideration: one of each targeting either production, comprehension, and interactive goals.

Once, the games were developed, children in each school participated in 9 sessions over a period of three weeks, each of the sessions consisting of the three games.

1) Game 1: Feeding Kaspar

In this game, Kaspar had 6 items of plastic food. Each item was split into two parts and attached with a Velcro tape. Kaspar then asked the child to cut a piece of food and place it close to Kaspar's mouth, this was repeated 6 times until the child had used all the food items.

The following specific SLC goals were targeted in this game related to comprehension:

a) Responding to simple questions when in a familiar context with a special person;
b) Understanding of single words in context, e.g. cup, milk, daddy;
c) Selecting familiar objects by name and find objects when asked, or identify objects from a group;
d) Understanding simple sentences (e.g. Throw the ball);
e) Identifying action words by following simple instructions, e.g. Cut the banana;
f) Beginning to understand more complex sentences, e.g. Put your toys away and then sit on the carpet;
g) Being able to follow directions;
h) Understanding use of objects (e.g. Which one do we cut with?);
i) Responding to instructions with complex elements, e.g. Cut the fruit and put it closer to my mouth.

Fig. 1 shows the interaction design used for the game.

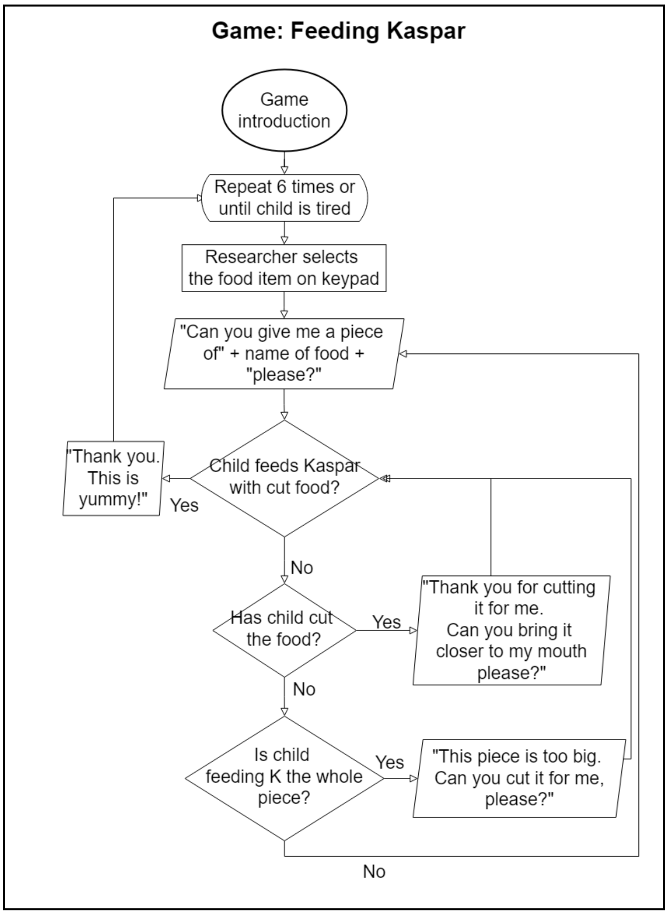

Figure 1. Flow-chart demonstrating the interaction design used in the Feeding Kaspar game.

2) Game 2: Pointing with Kaspar

There are 3 pictures of 3 animals in the room which are placed to the left, right and in front of the robot. In the first part of the game, Kaspar asks the child to point at a specific animal. For example, Kaspar says "Can you point at the elephant, please?". Once that child has done that, they receive positive reinforcement from Kaspar. After that, in the second part of the game, the child is instructed to ask Kaspar to point at one of the animals. Once they have done it, Kaspar then points at the animal and makes the animal sound. In this game, part one and part two alternatively repeat for 3 times.

The following specific SLC goals were targeted in this game:

Related to interaction:

a) Turn-taking;
b) Joint attention by pointing to share an interest.

Related to comprehension:

c) Understanding of single words in context is developing, e.g. cup, milk, daddy;
d) Following directions.

Related to production:

e) Using of single words or full sentences (depending on the developmental stage of the child);
f) Making requests.

3) Game 3: Tenses with Kaspar

In this game, there is the use of several images, shown on a tablet, portraying people doing daily activities (e.g. walking the dog, eating, cleaning, etc.). The researcher shows the child one of the pictures and Kaspar asks "What is my friend doing today?". The child then has to respond using either the present simple or the present continuous. After 3 pictures, then the child is shown a new picture and Kaspar says "This is a picture of my friend yesterday. What did my friend do yesterday?" to which the child then should answer using any form of the past tense during 3 pictures. After that, a new picture is shown again and Kaspar says "This is what my friend will do tomorrow? What will my friend do tomorrow?". The child then should answer the question using the future tense during 3 pictures again.

The specific SLC goals targeted in this game were the following:

Related to interaction:

a) Turn-taking.

Related to comprehension:

b) Responding to simple questions;
c) Understanding a range of complex sentence structures including tense markers.

Related to production:

d) Using different types of everyday words (nouns, verbs and adjectives, e.g. boy, go, drink);
e) Putting words together in full sentences;
f) Talking about people and things that are not present;
g) Using talk to explain what is happening, what happened and anticipating what will happen next;
h) Using a range of tenses (e.g. play, playing, will play, played).

The flow-chart on Fig. 2 shows the interaction design used for the game.

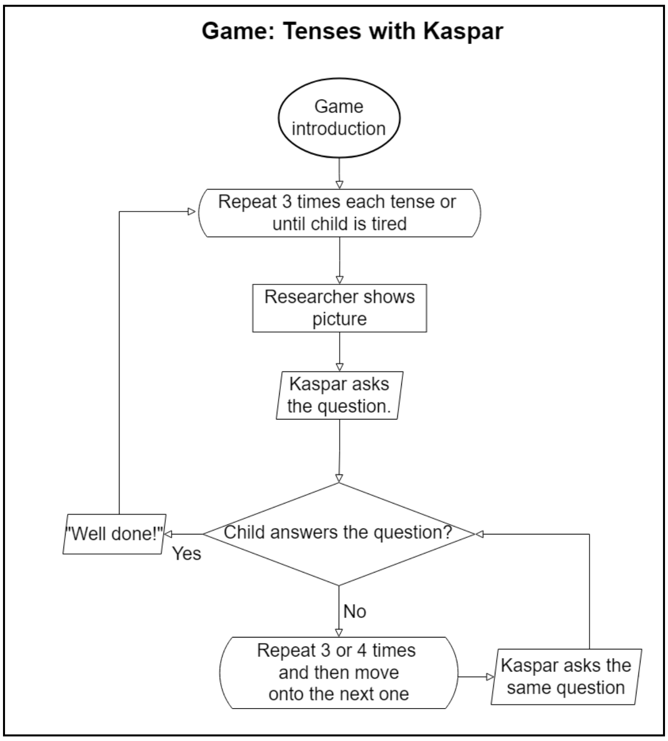

Figure 2. Flow-chart demonstrating the interaction design used in the Tenses with Kaspar game.

III. RESULTS

A. Video coding

All the sessions with the children were video recorded. The first two sessions and the last two sessions were coded using nVivo 12 with the intention assess the progress of the children. The videos were coded using a scheme that was specifically related to the games and both the production and comprehension of language. The videos were coded by a member of the research team and 20% of the videos were second-coded by a different member of the team. There was a substantial agreement between the two coders ($\kappa = 0.76$, $p < .001$). Any disagreement was resolved through discussion. See Table II for the video coding scheme.

A. Impact of the intervention

In order to compare the first sessions with the last sessions, a score x was computed for each game. First, a specific value was assigned to each behaviour of the coding scheme as shown in Table II. It is significant to note that Game 2 was related to both comprehension and production. So, both elements were evaluated and coded in this game.

TABLE II. Video coding scheme in Game 1, 2 and Game 3.

Behaviour	Value
Game 1 Food – Comprehension	
Child does something unrelated to the task	0
Child uses the wrong food	1
Child just picks the right food item	2
Child only cuts food OR places whole food close to the mouth	3
Child cuts food and places it close to the robot but not the mouth	4
Child cuts food AND places food close to the mouth	5
Intentional mistake	N/A
Game 2 Pointing - Comprehension, Production	
Comprehension	
0 Child does something unrelated to the task	0
1 Child says the name of the wrong animal	1
2 Child points at the wrong animal	2
3 Child says the name of the right animal but does not point at it	3
4 Child does not point at the animal but shows it in a different way	4
5 Child points at the animal when K requests it	5
Intentional mistake	N/A
Production	
0 Child does not produce any sound	0
1 Child produces unintelligible sounds	1
2 Child produces words with no meaning or with difficulty in the pronunciation	2
3 Child produces a fragmented sentence including the animal	3
4 Child produces a full sentence with grammatical or pronunciation mistakes	4
5 Child makes a request without mistakes	5
Child repeats what they hear	N/A
Intentional mistake	N/A
Game 3 Tenses - Production	
0 Child does not produce any sound	0
1 Child produces unintelligible sounds	1
2 Child produces words with no meaning or with difficulty in the pronunciation	2
3 Child produces a fragmented sentence related to the picture	3
4 Child produces a full sentence but the tense or the grammar is incorrect	4
5 Child produces the right sentence using the right tense form	5
Child repeats what they hear	N/A
Intentional mistake	N/A

After coding the videos, the score was computed following the formula below in which n is the number of times a child performs a specific behaviour and k is the specific value assigned to this behaviour:

$$x = \frac{\sum(n * k)}{\sum n}$$

As an example, the video coding presented in Table III,

TABLE III. Video coding example in Game 1 for calculating score x.

Game 1 Food - Comprehension	***k***	***n***
Child does something unrelated to the task	0	1
Child uses the wrong food	1	0
Child just picks the right food item	2	1
Child only cuts food OR places whole food close to the mouth	3	1
Child cuts food and places it close to the robot but not the mouth	4	3
Child cuts food AND places food close to the mouth	5	6
Intentional mistake	N/A	0

the formula and the score would be the following:

$$\frac{(1*0)+(0*1)+(1*2)+(1*3)+(3*4)+(6*5)}{12}=3.92$$

This way, for each coded session, each participant had one score for Game 1 (comprehension), two scores for Game 2 (comprehension and production) and one score for Game 3 (production) making a total of 4 scores per session. The scores from the first two sessions were averaged as well as the scores from the last two sessions. Therefore, there were 4 scores for each child that corresponded to their behaviour at the beginning of the sessions and 4 scores for each child in the last sessions.

A Wilcoxon Signed Ranks test comparing the average scores from the first two and the last two sessions showed a significant improvement in Game 1 (Z = -2.534, p = .011), Game 2 (comprehension) (Z = -2.371, p = .018), Game 2 (production) (Z = -3.583, p < .001) and Game 3 (Z = -3.061, p = .002).

The impact of the intervention sessions can be observed as presented in Fig. 3.

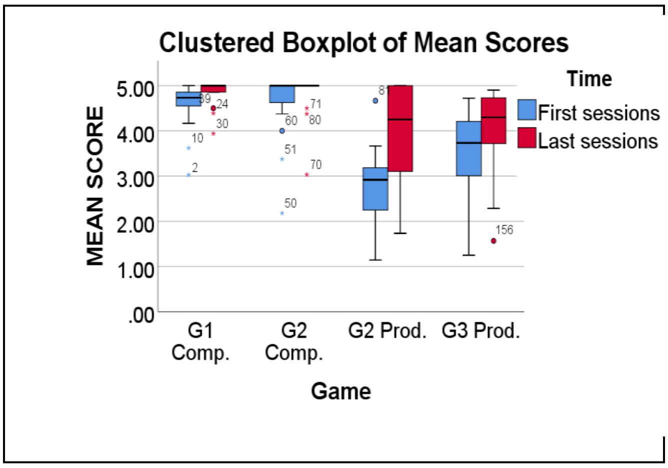

Figure 3. Differences in participants' mean scores in the first two and the last two sessions of Game 1, Game 2 and Game 3.

IV. Discussion

Results of the study suggested that there was significant improvement in the children's speech and language communication skills from the first two sessions to the last two sessions. The findings further suggested that the area that improved the most is the production of language in Games 2 and 3, indicating that most children ended the sessions making requests, and creating full sentences, explaining the actions of other people in the past, present and future.

Considering the research questions, results show that the interactive games with Kaspar made a significant improvement on the children's speech and language, especially in language production and certain aspects of comprehension and turn taking (RQ1). This suggests that humanoid robots such as Kaspar can be used to help children with learning disabilities to improve their speech, language and communication skills, further supporting earlier findings of [15] and [16] with Nao and the Rasa robot. Some measurable impact on children with learning disabilities (RQ2) and SLCN could be clearly seen on the video coding analysis.

Our future research plans involve further analysis of the data, including the analysis of pre- and post-intervention assessment questionnaires filled by the participants' teachers. This would provide further information on the effectiveness of the interventions, indicating whether teachers could see any improvements in the pupils' speech and language skills.

V. Conclusion

We embarked on this study to assess the feasibility of using Kaspar robot for Speech, Language and Communication therapy in the context of education for children with learning disabilities. Our results affirm feasibility, leading us to think that this type of robotic interaction is the right path to follow to help the children improve their communication skills. In addition, the results open new directions for our future research. Based on the findings of the current study we aim to investigate possibilities of robot-assisted therapy for SLC further by enabling longer-term use of our methods in special needs education.

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