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Tale of a robot: Humanoid Robot Assisted Sign Language Tutoring

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Abstract—**There is an on-going study which aims to assist in teaching Sign Language (SL) to hearing impaired children by means of non-verbal communication and imitation based interaction games between a humanoid robot and the child. In this study, the robot will be able to express a word in SL among a set of chosen words using hand movements, body and face gestures. Having comprehended the word, the child will give relevant feedback to the robot. In the current study, we propose an interactive story telling game between a NAO H25 humanoid robot and preschool children based on Turkish Sign Language (TSL). Since most of the children do not know how to read and write, and they are not familiar with sign language, we prepared a short story including specially selected words which is performed by the robot verbally and with sign language as well. The children are expected to give feedback to the robot with matching colour flashcards when it implements a word in sign language. The robotic event covered 106 preschool children. The aim is to evaluate the children's sign language learning ability from a robot, and comparison of these results with the results of video based studies.**

Keywords- Humanoid Robots, Interaction games, Non-verbal communication, Sign Language

I. INTRODUCTION

Sign Language (SL) is a visual language that is comprised of hand movements, body and face gestures. Hearing impaired children have chance to learn this language as their native language even before they learn written language on condition that their parents are hearing impaired as well. Language acquisition, which is an extremely crucial process for brain development and intelligence, is completed at ages of 2 or 3 years. Hence existence of sufficient native language materials and their employment during education is of great importance for preschool training.

Utilization of television and computer has become widespread for the purpose of teaching sign language to hearing impaired people. A comprehensive research is being held in Turkey to teach Turkish Sign Language (TSL) by videos and to understand sign language performed by people. This study involves research on recognition and classification of hand and face gestures [1, 2]. In addition, a TSL tutoring software [3] has been implemented.

This study is a part of an ongoing research, which aims to utilize humanoid robots for assisting sign language tutoring due to the incompetency of 2-D instructional tools developed for this goal and the lack of sufficient educational material. In the proposed system, it is intended that a child-sized humanoid robot is going to perform various elementary TSL words to assist teaching these words to hearing impaired children. This will be achieved through interaction games based on non-verbal communication, turn-taking and imitation that are designed specifically for robot and child to play together.

Within this study, first a survey has been carried out to evaluate the success of robot tutors within the video based studies. A subset of sign language words which can be implemented by the Nao robot were chosen, and for each word selected, a video which displays the robot performing the sign language expression has been prepared. The corresponding videos of sign language representations by human teachers are available within the TSL tutoring software [3]. For the test study, following the demonstration of the robot's and human teacher's performances of several selected words from TSL by videos, a number of participants have been demanded to fill out a questionnaire regarding the success of the robot's performance in matching to the correct human implementation. The survey consisted of several groups of participants of different age groups and test environments such as class studies with adult participants who are not familiar with sign language, adults who know sign language, teenagers and preschool children having the test as a web based game.

Our main focus of attention is using the real robot within interactive games. As a primary step, we had the currently proposed study with the 106 preschool children from the nursery of our university. In this novel study, the robot tells a story including the special words tested in the previous study with adult participants, and also realizing the signs of the words. The children are asked to assist the robot by showing the colour flashcards matching the signs. The performance of the children are evaluated through the play cards they filled after the tests, showing if they learned the sign language words or not.

The details of this study and the previous studies within this project will be found in the experiments and results sections.

II. LITERATURE SURVEY

In 1977, a robotic hand that could spell words by utilizing the manual alphabet was constructed to assist hearing-impaired individuals. The upgraded version of this model, namely "Dexter II", was also able to demonstrate the letters that required wrist movement as well. In 1992, another

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robotic hand, which was able to produce letters received from a TTY (text telephone) in fluid movements, was developed. Finally, in 1994, the most advanced version, Ralph (Robotic ALPHabet), was produced. This robotic hand with the capability of finger spelling was controlled by a menu-driven user interface on a remote computer [4, 5]. In these studies, the robotic hands were not connected to a robot.

Various studies have been carried out for the recognition of different sign languages. A system that recognizes 40 words in the American Sign Language, with 90% precision has been implemented [6]. Another study states an 80% success rate for detecting 95 words taken from the Australian Sign language [7]. Regarding the Japanese Sign language, a total of 52 words, 42 of which are represented by the finger-alphabet, have also been adequately identified [8].

There is also a study that recognizes 19 words from the American Sign Language by utilizing Hidden Markov models [1]. These words are expressed by the movements of the head and the two hands. The program flow commences with the user repeating a sign language word after watching its corresponding video. The recorded movements of the user are analyzed to determine whether the sign language word has been performed appropriately. A success rate of 99% has been reported for the recognition of words expressed solely by hands and a success rate of 85% was achieved for the classification of words performed both by hands and by the head. Various other studies on sign languages such as the recognition of hand shapes and movements or the classification of facial gestures have been carried out in order to analyse and assist in teaching sign languages [9-14].

There are several successful user studies on non-gesture communication through imitation based interaction games with humanoid robots and human participants [15, 16]. To achieve interaction, a special drumming game titled as "drum-mate" with gestures provided by the robot to motivate successful turn-taking were studied in [16-19]. We aim to extend our previous work on non-verbal turn-taking games based on interaction and imitation to our current study.

Several virtual reality games have been implemented for the hearing-impaired children [20, 21]. Among these studies, CopyCat is a vision-based interactive game which intends to help teaching the American Sign Language. In a project which is called ICICLE (Interactive Computer Identification and Correction of Language Errors), it has been aimed to establish an instructive system for the hearing-impaired children to provide them with individual lectures and guidelines by computer-aided commands [22]. [23] reports a study consisting of the world's first Thai-sign-language-reading humanoid robot Dinsow, which recognizes sign language with the aid of its cameras, and will be used to help hearing impaired people.

III. EXPERIMENTS

This study is a part of an on-going research that aims to help teaching TSL to hearing-impaired children via interaction based games between robot and the child. The H-25 Nao robots is used in the user-studies, as they have hands and fingers to implement most of the sign language words, and appropriate to use in interactive children games due to its expressive face, small size, compact shape, and toy-like appearance.

The Nao robot, which has a height of 0.57 m. and a weight of 4.5 kg., is a system with 21-25 degrees of freedom, 500 MHz processor, two cameras, sonar sensors, and force-sensitive resistors [24].

In this study, a subset of the most appropriate words that can be demonstrated by the movements of a Nao robot have been determined. The physical limitations of the Nao robot makes it hard to implement some of the words. One of the reasons for this is the fact that the Nao robot has only 3 depended fingers while most of the words from the TSL are performed by using 5 fingers (mostly independent, i.e. one pointing a part of the face and other 4 are curled). We plan to move the project on a new robotic platform with 5 fingers and more DOF on the arms and wrist as a future study.

The goal of the study was to determine whether embodiment and test environment have an effect on how users perceive sign language, and if robots can be a useful assistive tool for sign language tutoring. By the aid of the proposed system, distinct success rates for robot and human tutors will be extracted. Regarding the TSL, no matter how professional the teacher might be, each individual has a different style, which causes difficulty in learning in case the instructor is replaced. In the proposed system, it is intended to show that the robot tutor achieves a similar success rate with human teachers. In this way, it is planned that tutor independent TSL teaching will be achieved. Here, it should also be noted that the aim of the proposed system is to develop a fast, simple, motivating tool with easy update facility that allows children to test their knowledge. The proposed system is expected to assist human teachers rather than to form a substitute for them.

A. Video based evaluations of adults

First, a survey, which intends to evaluate the performance of the Nao robot simulator [25] for demonstrating a number of chosen TSL words, has been carried out in this study. The survey has been carried out both for university students who have little or no acquaintance with the TSL and the students attending second degree TSL courses. To study the age effect, 25 secondary school students were asked to take part in the study under the supervision of their class teacher. Unlike the first two studies where one experimenter was present in the class during the study, and guides the study, this third case was applied as a web based online game.

1) Adult participants with no acquaintance with Sign Language

In the first part of the survey, 40 people (16 male, 24 female) participated. A subset of simple TSL words from daily life, were chosen for the survey (5 words: car, friend, dad, three, and table). These words have different difficulty levels for implementation with Nao robot with 3 fingers, and are selected specially to evaluate the affect of physical limitations on the realization and recognition of sign language with robots. Detailed discussion will be placed in the [26, 27] due to page limitations of this paper.

During the execution process throughout the survey, firstly the video of the robot performing the sign language

word has been displayed to the participant. Subsequently, a number of human teacher videos taken from the TSL software have been shown for the participant to identify the video that mostly resembles that of the robot. In each of the TSL software videos, a specific TSL word is performed by a human teacher. Finally, the participants were asked to reveal which word was most successfully expressed by the robot.

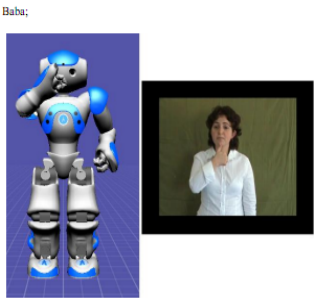

Figure 1. Videos corresponding to the realization of TSL word "baba"(father) by Nao robot simulator and a human teacher.

In this survey, having chosen the most likely human teacher TSL video for the robot's expression, the participant will then assess a score of resemblance for the corresponding two videos of human and robot performance. Hence, if the participant is able to come up with the correct choice, he/she will determine a score for the corresponding TSL video. Otherwise, he/she will be evaluating a wrong choice, thus endeavouring to assess the resemblance between the robot video and an irrelevant human teacher TSL video.

The questionnaire for this survey finally asks about the most and the least successful robot/human teacher TSL video pair according to their similarity with each other. The questionnaire also interrogates the reasons for the failure of robot performance for expressing a TSL word such as; a) physical appearance of the robot b) physical incompetence pertaining to the robot c) software inadequacy of the Nao robot simulator d) other reasons.

2) Adult participants with Sign Language acquaintance

As a test case, the survey is also done on a class of second degree sign language students (11 females and 1 male). Although the words and the videos are the same with the first survey, the way we ask the questions slightly changed. Before giving the choices to the sign language professionals, we first wanted to get their unbiased opinions and guesses about the videos.

The second questionnaire is comprised of four sections. Firstly, the participant is asked to watch a video containing a Nao simulator representation of a TSL word and then to guess the word that the simulated Nao attempts to perform. Secondly, the participant is expected to choose the correct video, which resembles the most to the Nao's demonstration of a given TSL word, among a number of videos each of which displays the human teacher performance of a specific TSL word. In addition, the resemblance ratio among these two similar videos is required to be graded by the participant based on a 5-scale. This part is the same with the test applied in the first survey. Thirdly, the participant is requested to select a certain word that he/she thinks to correspond to the video of the Nao simulator representation among a number of given words and to rank the resemblance ratio as well. Finally, the participants were asked to evaluate the videos of the robots as the most and least successful word implementation of the robot.

3) Teen participants with no Sign Language acquaintance

One of the motivations of this project was to share the sign language education materials with as much people as possible, discarding the proximity, cost and technical challenges. Therefore, we converted the experiment material into an online interaction game and test with secondary school students to see if age and experience will have an effect on these results. The site is in Turkish Language and the results automatically go to the statistical pool [28]. Currently, the site contains the videos of real Nao robot. But for consistency we used the simulated Nao videos which were used in the first two sections during the tests. 25 students (9 males and 16 females), of age group 17-19 from a secondary school used the online test by the supervision of their teacher. Unlike the first two experiments, the experimenters were not present in the experiment area and did not have a demo or explanation about the experiment.

Also there is a version of this online game for children with simpler instructions, colours and pictures (i.e. ice-cream cones based rating system for evaluation of videos), which was designed under the supervision of nursery psychologists and to be tested in nurseries and primary schools [28]. The first study included 16 preschool children (6 years). The children were accompanied only by their class teacher during the test. The results were less successful compared to the results of adults [26]. This will be due to the lack of social interaction in the 2-D teaching material. We expect the presence of the physical robot will affect the performance of the children positively.

B. Nao's tale: An interactive story telling humanoid robot with Sign Language

Our current study is an interactive game with real Nao H25 robots. The robot was telling an interactive story with sign language and children could assist the robot using special flashcards illustrating the signs in the story. A test including the signs in the story follows the story telling as well. Story telling robots were used in the literature before to model human-like gaze behaviour [29]. As stated in [17], we expect to observe a positive effect of the physical embodiment of the robot within a social interaction context, on the performance, and interaction of the children, compared to the video based studies.

We had experiment with 106 preschool children (6 years old-- in Turkey the primary schools start at 7 years) from the nursery of our university. The experiment took place in the big atrium of the nursery as a demo event rather than a strictly controlled laboratory experiment due to the restrictions and limitations caused by the age and quantity of the children. This work is one of the biggest robotic events in the world with this age group to the best of our knowledge. Our previous robotic experiment based on interaction games with a drumming robot included 68 primary school children of 7-11 age group in UK [17].

The children were sitting around the robot and the robot was placed on a small table. We prepared papers with the story where the special words were shown with flashcard pictures. First we had a demo with one of the experimenters. Then one of the children was chosen to play with the robot (Figure 2). Whenever the robot does the sign, the child was expected to hold the relevant flashcard to the robot (Figure 3). If the flashcard was not the one that the robot expected to see, then the robot's eyes go from green to red, then they become green again. If the flash card is correct then the robot says the name of the flash card and continues to the story until the next sign is done (Figure 4).

Figure 2. A child listens to the robot's story

Figure 3. Child interactively play with robot to complete the story

The story [APPENDIX B] was written by us specially to include all the sign language words (5 words: car, friend, dad, three, and table) we tested in the previous experiments (see the section on Video based evaluations of adults). Therefore, it will be convenient for comparison of the different age groups and test setup since the test is based on the same words. We design the story so that it was simple, and easy to understand and remember, yet still interesting for preschool children. Also the story was specially arranged so that every special word appears exactly twice in the story, mostly at the beginning of the sentence (these make it easier to detect signs from the story –it is required in our parallel study, which includes detection of sign language by the robot, as well). Not more than two signs were used per sentence. Although Nao has text-to-speech feature, we could not find a natural sounding Turkish text-to-speech program, and to fit the story better, we asked a 6 years old to tell the story and use her voice on the robot. Hearing the story from a child's voice had a very positive effect on the children.

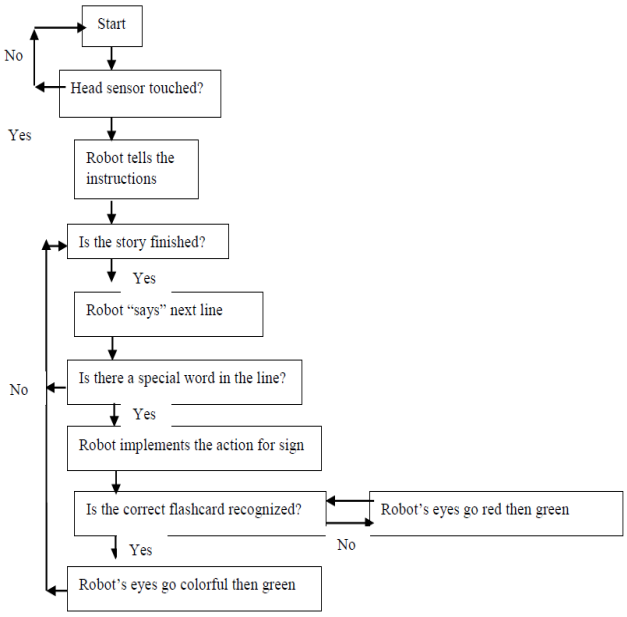

Figure 4. Game flow chart

After the story was read and implemented by the robot, the experimenters explained that the robot would play a game with the children. The robot realized the signs one by one and the children were asked to put the sticker of the relevant word to their story cards. There were also slots for their names and picture of a boy and a girl which they can choose according to their gender for demographic information. Since most of the children did not know how to read and write we had to simplify the questionnaire and test instructions as much as possible. Details of the implementation of the program flow are presented in (APPENDIX C).

Unfortunately, due to the high number of students we could not get the completed story cards immediately. But the teachers of each class were asked to help children to fill out the cards and return them as soon as possible. We also recorded the robot's telling the story, all the instructions and the test at the end as video. We included the video of the story told by one of the experimenters and several dance videos of the robot which we promise to show to the children as a reward. We handed them to all classes, and the teachers told us they will show them to children again, in case due to the crowd some children might not see all the details, and hand out the completed story cards for feedback, afterwards.

IV. RESULTS

As stated above, the demo and the tests were implemented with 106 children of 6 years. Due to the high number of children and their small age, the teachers of each class (each class consists of 20-21 students and 2 teachers per class) assisted us in collecting the results and they reported the results to us. One class was chosen as pilot class by the school and the detailed results of that class (10 girls and 10 boys) was reported by the school in details. The report suggested that, out of 20 children who attended the event, 18 children (9 boys and 9 girls) completed the play cards with correct order (0 failure), and the children showed very much interest and were successful compared to their age group in

terms of similar skills. The other classes also show similar success rates. Moreover the children liked the event and although none of them knew sign language before they started to imitate signs after the robot. Although both girls and boys showed same success, the teachers reported that boys were more interested on the robot. They even asked to take the play cards to their homes to show to their parents. Despite of the fact that the number of children attending the activity was quite high and the age group was too small to perform a strictly controlled experiment/demo, the autonomous interaction game with the robot was implemented successfully. The teachers and the school gave very promising and positive feedback and asked if they can use the videos and video based tests in other age groups and the following semesters as a part of their activity schedule.

We also had individual laboratory trials before the robotic event with the physical robot. The results of the laboratory trials of 5 participants are as follows:

TABLE 1. TRIAL RESULTS OF NAO'S TALE

Age	# of Successful words	# of Failures
6	5	0
6	5	0
5	4	1
22	5	0
22	5	0

As stated in the Table 1, the results of the trials were quite promising. The 5 year old participant was accompanied by her mother and father, and more surprisingly, she perceived the signs and the game better than her parents (they tried to assist her and change her answer in one trial but she insisted in her true answer).

The human tutor version of the game was not tried due to the time limitations. We will test and compare it to the current results, shortly.

Note that, although the success rate is quite high, the test was not so trivial. The children were asked same signs as the adults and teenagers where, including the sign language professionals, the success was not as high as this age group. Some words (i.e. "three") had quite low success rates by some groups (teenagers, children –web based studies). The discussion on the results of adults' video evaluation is presented in APPENDIX C. More discussion on these results can be found in [26]. These words were specially selected, since realizing them perfectly was beyond robot's physical capability. But in this experiment we saw that if they were taught within a relevant story/context than their identification/recognition increases. This is a very important gain for us and we will use this to improve our study with the hearing impaired children.

V. CONCLUSIONS & FUTURE WORK

This novel study has been carried out as part of a more comprehensive research, which aims to help teach sign language to hearing impaired children by generating interaction based games between the robot and the children. To the best of our knowledge, this is the first and only study on the usage of humanoid robots in both producing and recognizing gestures for sign language tutoring within interaction games.

In the first part of the project, a survey has been carried out to evaluate the performance of Nao robot (simulated) for expressing certain words from the TSL in video based studies. After examining the robot's video and several corresponding human videos for every word, the participants were asked to fill out questionnaires in order to assess the resemblance between the robot and the human teacher to determine whether the Nao robot is capable of expressing SL words. Several environments (i.e. class studies, web based studies) and different user groups (i.e. adults w/o sign language acquaintance, teenagers, and preschool children) took part in the study, and the results were studied according to age, gender, SL acquaintance and environment differences.

Although the physical limitations of the robot does not allow the implementation of all words in the domain (i.e. the ones that require 5 fingers or some complex upper torso motion), and most of the participants were chosen from naïve people who do not know robots or sign language, most of the words were recognized with success in the video based studies. There was bias related to the familiarity of some words, or the fact that there are several words whose implementation looks very familiar due to their close meaning (i.e. father -uncle). The detailed analysis and discussions on the results of the video based studies are presented in [26].

In the current study, we designed an interaction game including the words and signs from our previous study with adults. We implemented a story telling game partially in sign language, where the children interact with the robot and assist the robot with colour flashcards to indicate correct words matching the robot's signs throughout the game. We tested the game with 106 preschool children in a collaborating nursery. The reactions of the children was very promising, although they did not know sign language before, and they were not hearing impaired, they were imitating the robot's signs soon after the demo. The first results from our laboratory trials with same age groups, and the results from the pilot class showed that we had very couraging success (at worst, 4 successful answers out of 5). This shows even if the robot has physical limitations, if the education is given within a relevant context/story which is also interesting and suitable for this age group, the success rate increases significantly. This is one of the biggest gains of this study and can be applied to the other education projects for the disabled children, as well.

Also to the best of our knowledge, this event was one of the biggest robotic events with children in the world, and although the participant number was very high and the participants' age group was very small, the study was very successful, and the results are very promising. Moreover, the children and their families were quite interested in the idea of teaching children sign language with robots, which was one of our biggest goals.

As a future work, we plan to extend the game with two robots (tale of two robots) so we can add more characters in the game and not just implement words but can have

sentences and conversations with sign language. We currently implemented more than 40 daily used words in TSL, and 9 words in American Sign Language (ASL) on Nao robots. Also we plan to use an additional robotic platform with five fingers and more DOF on arms to express the signs better. As stated before, we have collaborations with other robotic and vision research groups to implement the other side of the game where the robot will understand the children's realizing the signs and both can interact with sign language.

Currently, there is also an on-going study within our project to imitate the sign language of a human teacher by using motion trackers. This will decrease the time and effort to model the SL words on robot which is otherwise done manually and take 1-2 hours each to perfect. Every human has their own way of producing sign language like 'accents', and small differences in gestures can mislead people, especially if they are not familiar with the language. Our aim is to teach robot sign language from different human tutors and produce smooth and natural-looking gestures.

We implemented also a version of this interactive game with Nao robot in English (the story and instruction parts) and repeat this demo as an open robotic event with volunteers including children during the Robocup 2011, Istanbul, Turkey in July, 2011 with the support of Aldebaran company.

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APPENDIX A

Nao's Tale


üç

(3) close


arkadaş

(friends) decided to go to picnic to the


baba

forest. (Dad) drove them to picnic with his red


araba

(car). When they arrived they put their food on the


masa

(table). They had very delicious food and cakes.


üç

(3)


masa

little rabbits suddenly jumped to the (table). Everything


baba

falls on the ground. (Dad) said "don't worry; we can continue


arkadaş

to picnic at home". (Friends) arranged their belongings


araba

and got on the (car), and drove to their home to continue to picnic. Little rabbits continue to play in the forest, too.

Please put relevant stickers to the boxes below

1	2	3	4	5

Name: Gender:

APPENDIX B

Discussion of the Results on Adults' Video based Study

TABLE 2. CHOSEN TSL WORDS

	Turkish Word	English Meaning
Word 1	Araba	Car
Word 2	Arkadaş	Friend
Word 3	Baba	Father
Word 4	Masa	Table
Word 5	Üç	Three

Only the results of the adults and teenagers are included in this part. To determine whether or not participants got more answers correct than suggested by chance, a series of Chi-Square(χ^2) tests were run to determine for which of the words the participants correctly matched the robot's signing to the human signer.

The results suggest that for Words 1, 2 and 4, the participants were more likely to correctly indentify the sign than not, while this was not the case for Words 3 and 5.

For Word 1 there was a trend approaching significance (χ^2 (2) =5.37, p=.068) where participants with knowledge of sign-language were less likely to get it wrong, while participants with no knowledge of sign language were more likely to get it wrong.

For Word 2 there no significant results for knowledge of sign-language (χ^2 (2) =3.62, p=.17), nor for gender (χ^2 (1) =2.14, p=.15)

For Word 3 there was a significant effect for knowledge of sign-language (χ^2 (2) =9.01, p=.011) where participants with knowledge of sign-language were less likely to get it wrong, and more likely to get it right, while the opposite was true for participants with no knowledge of sign language.

For Word 4 there was a significant effect for knowledge of sign-language (χ^2 (2) =7.43, p=.024) where participants with knowledge of sign-language were ***more*** likely to get it wrong, and ***less*** likely to get it right, while the opposite was true for participants with no knowledge of sign language.

For word 5, There was a significant result for gender (χ^2 (1) =4.393, p=.036), where males were ***more*** likely to match it correctly, while females were less likely to do so.

In terms of relationship between age and knowledge of sign-language, The professional sign-language interpreters were excluded from the analysis and the relationship between knowledge of sign-language and age was investigated using cross-tabulation and tested using χ^2-tests. This analysis found no significant relationship between age and knowledge of sign-language($\chi^2(6)=6.66$, p=.35), suggesting that the samples did not differ from each other in terms of knowledge of sign-language.

Word 5 and Age: There was a significant differences between the age groups in terms of correctly matching Word 5(χ^2 (2) =42.78, p<.001). The participants in the 13-17 and 18-22 sample were unable to match this correctly.

APPENDIX C

Nao's Tale: Robot's model