ROBOT- ASSISTED SPEECH AND LANGUAGE THERAPY FOR CHILDREN WITH HEARING IMPAIRMENT

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Abstract: Robots become very popular in research on learning, education and rehabilitation especially for children with disabilities. Our paper presents a study of a robot-assisted speech and language therapy session with eleven hearing-impaired children who use cochlear implant(s). The study explores the opportunity of using a humanoid robot for the development of speech, language and listening skills. NAO cannot articulate, therefore, children cannot do lip-reading. We considered that this special characteristic of the robot would provoke the participating children to use actively their listening. Results showed how NAO assisted speech and language therapy sessions with hearing-impaired children who use two different communication modalities – total communication and auditory-oral.

Keywords: NAO humanoid robot, robot-assisted therapy, social robot, speech and language therapy, hearing impairment

ПРИЛОЖЕНИЕ НА АСИСТИРАНА ОТ РОБОТ ЛОГОПЕДИЧНА ТЕРАПИЯ ПРИ ДЕЦА С УВРЕДЕН СЛУХ

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Резюме: Роботите все по-често се включват в научни изследвания, свързани с интервенции, обучение, рехабилитация на деца с увреждания. Статията представя проучване на асистирана от робот логопедична работа с единадесет деца с увреден слух, които използват кохлеарен имплант(и). Проучването изследва възможността за използване на хуманоиден робот за развитието на слуховите умения у деца със слухова загуба, респективно и стимулиране на езиково-говорното им развитие. Роботът NAO не може да артикулира, следователно децата не могат да отчитат. Считаме, че тази специфична характеристика на робота е уникална и ще провокира участващите деца да използват активно слуха си. Децата с увреден слух, които участват в изследването използват две различни комуникативни модалности – тотална комуникация и слухово-орален подход. Резултатите от изследването демонстрират взаимодействието между робота и децата по време на логопедичната

сесия. Учениците, които използват вербалната комуникация се справят по-добре с игрите, разбират по-ясно инструкциите на робота и дават по-голям брой верни отговори в сравнение с останалите участници, които използват тотална комуникация.

Ключови думи: NAO хуманоиден робот, асистирана терапия с робот, социален робот, логопедична терапия, слухови нарушения

INTRODUCTION

The number of people with hearing loss is increasing every year. According to the last information by World Health Organization there are 34 million children with hearing loss worldwide (WHO, 2020). Any hearing loss affects the child's ability to communicate with others. Even mild hearing impairment can reduce the listening and spoken language, academic skills. In addition, it may have negative impact on social interaction. Early identification and intervention are very important for child development. Fitting with appropriate hearing device (for example hearing aid, cochlear implant) must be followed by speech and language therapy. It is not easy to predict the degree of benefit from the cochlear implant (CI) of children (Cooper & Craddock, 2006). Different factors can influence the outcomes from the cochlear implantation such as: unsuccessful implantation, unsuccessful therapy, age of the impairment of the hearing, late identification of hearing loss, the number of active electrodes of the implant, IQ of the child (Hummes & Bess, 2008), nonuse of the implant, etiology of hearing impairment, mode of communication (Paul & Whitelaw, 2011). Choosing the appropriate individual rehabilitation program allows effective communication for the child.

The majority 92 – 96 % of hearing impaired children are born in families with hearing parents (Welling & Ukstins, 2017). These parents face multiple challenges like choices with technologies, language, therapy approach, education. Parental decisions have to be made, and often within a certain timeframe of critical period for language development (Flaherty, 2015). The family of a hearing-impaired child has to decide what type of communication modality to use with their child – verbal or manual (Marshark & Hauser, 2012). Study of Crowe et al. (2014) investigates the use of communication modality in families of children with hearing loss between three to nine years of age. They found out that the oral speech is used by 96.6 % and the signing is used by 20.9 %. The parents choose the communication modality for their children depending on source of information – medical professionals, the amplification, speech therapist, access to intervention, other parents of deaf children, family, own research, communication modality used in family, languages in family and community, child's individual needs, accessibility of communication, type and degree of hearing loss, child's future life (Crowe et al., 2014).

According to Fitzpatrick et al. (2016) and Welling & Ukstins (2017) the published data about the effectiveness of using oral or sign language in intervention with hearing-impaired children is not enough and does not illustrate clearly which is the best communication approach. Children who undergo therapy program within the auditory-oral approach use amplification. They are listening to their interlocutor and paying attention on lip reading and body language at the same time. Total communication approach combines the use of spoken language simultaneously with manual methods i.e. sign language and finger spelling. Another very strict approach is the auditory-verbal. The use of lip reading or use of other non-verbal cues are not allowed to facilitate the communication (Welling & Ukstins, 2017). Auditory-verbal approach is child-directed. It is using play and it is based on the child's individual interests. The therapy with auditory-verbal approach involves strategies that support the turn-taking and joint attention; hence, it facilitates the development of speech, language and listening of the child (Estabrooks et al., 2016: 286). When applying this approach during the therapy sessions, speech and language therapist must stay in position that does not allow lip reading. Some years ago, the professionals used to cover their mouth in order to provoke the child to use actively his/her amplification device (cochlear implant and/or hearing aid) to hear the sounds of speech. In publication from 2016 Estabrooks et al. encourage speech and language therapists to behave more naturally during auditory-verbal therapy. They recommend using strategies to eliminate lip-reading but without covering their mouth, because this is an atypical act in social interaction. They believe that hiding the mouth might disrupt sensorimotor input during infancy and may affect the development of speech motor control. It can also cause stress in young children and it might have in turn, negative effect on speech perception (Estabrooks et al., 2016).

The speech and language therapist uses many supporting tools during the sessions in order to achieve the therapeutic goals with hearing impaired children. Some of these are toys, pictures, books, audio recordings. There are more advanced tools, such as computer programs and games, special applications used for assessment and/or therapy, in order to develop listening skills, speech and language. Technology becomes part of everyday life nowadays. There are many examples of computer-based technology used in speech and language therapy. The technology can provide opportunity for assessment of voice, speech, listening and language. It can give biofeedback to the client with communication disorder during the therapy process. In some cases, technology can adopt the level of difficulty in an assessment or therapy task according to the individual level of a particular client.

Another very attractive alternative technology is the robot. Therapy assisted by a robot is a scientific field that is expanding very quickly. People use robots for companionship. Robots can be part of the education and therapy. The published

studies on use of robots in rehabilitation are rapidly increasing during the last decade. Robot-assisted therapy can provide automated diagnosis, monitoring of the child progress, semi-automated running of therapeutic programs, as well as playing roll of mediator in interaction between the child and speech therapist (Belpaeme et al., 2013).

The research interest for robot-assisted therapy for children with disabilities increases. Research on the robot-assisted therapy conclude that children perceive interaction with the robot as it is a social partner, as a peer in play. Even more, children desire to initiate communication with the robot (Nalin et. al, 2012). Very popular are the studies about application of robots in the therapy of children with disabilities such as participants diagnosed with cerebral palsy (Malik et al., 2014) or Autism Spectrum Disorder (ASD) (Robins et al. 2005; Arendsen et al., 2010; Hamzah et al., 2014; Ioannou et al., 2015; Lee & Hyun, 2015; Srinivasan et al., 2015, Wood et al., 2019). Robot-assisted therapy is also applied in cases of children with delayed speech development (Zhanatkyzy et al., 2019). Humanoid robots show particular effectiveness with ASD children. They are safe and with predictable nature of the interactions, it facilitates. Robots are simple and predictable with basic conversational function. These capabilities allow the robots to be used as mediators, assistants of the professionals in therapy sessions, with the parents at home or with the child's peers at school, at hospitals (Lee & Hyun, 2015, Wood et al., 2019; Cifuentes et al., 2020).

The studies that explore robots' use with hearing-impaired children are limited. Scientists developed a robotic voice simulator that is used in speech therapy sessions with hearing-impaired people. It consisted of motor-controlled articulation organs – a vocal tract with vocal cords, a nasal cavity. The robot imitates the vocalization and speech of the therapist. In turn, the hearing-impaired client observes the robots' articulation and learns how to produce intelligible speech through repeating the correct articulation (Sawada et al., 2008; Kitani et al, 2008, Kitani et al., 2011). Later this talking robot is modified with text-to speech system. The aim of this design is to enhance the therapy sessions with people with hearing impairment. The movement of the robotic articulators reproduces the typed text or character and therefore the client observes the articulation movements and try to imitate the correct pronunciation (Vo Nhu & Sawada, 2017). There are studies that investigate the use of robots for interpretation of sign language. In a research, the humanoid robot NAO is involved as an assistant in story telling by signs from the Turkish sign language (Kose et al., 2011). This robot has a specific hand with only three fingers. This is a limitation of NAO if it is applied for sign language interpretation. The robot cannot present all range of signs that are used in manual communication. Later, the researchers implement in their study another robotic platform that has five fingers. This robot has the ability

to recognize signs and to give a feedback as signs, visual or vocal. The main purpose of their research is to teach sign language to deaf children by robot-assistance in games (Uluer et al., 2015). Recent research in Germany focused on speech-to-sign interpretation by developing robotic arms for humanoid robot (Homburg et al., 2019).

Some preliminary results of our first study in using the robot NAO with hearing-impaired children were presented on a conference in 2016. We used the robot as a tool for assessment of listening and speaking skills in a small group of deaf children (Polycarpou et al., 2016). Our researcher team implemented for the first time the humanoid robot NAO in a follow up study of auditory-verbal therapy sessions. Six children with hearing impairment who use amplification (hearing aid or/and cochlear implant) play with NAO. The games design is developed according to the auditory-verbal approach. The robot assisted the speech and language therapy sessions in a period of six weeks. All children demonstrated improvements in their listening skills (Ioannou & Andreeva, 2019).

The aim of the present experiment is to continue investigating the possibilities of humanoid robot-assisted speech and language therapy. The participants are children with hearing impairments, users of CI and two different communication modalities. The robot NAO cannot articulate, because it does not have moving lips. That does not allow lip-reading. This unique characteristic can provoke children with hearing impairment to use actively their listening in interaction with the robot – "assistant" of the speech and language therapist.

Method: The humanoid robot NAO from Aldebaran Robotics, now SoftBank Robotics, was selected for this study. It is 58cm tall and has human-like features. NAO has still face and cannot show facial expression and articulation. The robot "emotions" were introduced with its body language and the voice modulation of recorded speech.

The study was organized in five stages presented on Figure 1. First, the "assistant" of the speech and language therapist was chosen – humanoid robot NAO. This particular robot exhibits features like a human being. NAO has the ability to walk, dance, recognize images, faces and objects, speak, as well as respond to speech instructions and react to other sounds of the environment. The second stage involves development of game-like applications that are deployed on NAO. The activities of the speech therapy session are robot-assisted and they aim to provoke students to listen actively, to understand and use verbal language. The third stage is due to find families with hearing-impaired children who agreed to participate in the study. Parents were acquainted in advance with the aims and the process of the experiment. All of them had signed a consent document. After that, the experiment was conducted with the participants in a real environment. The last stage is for description, evaluation and analysis of the collected data. Belpaeme et al.

(2013) share the opinion that evaluating the effectiveness of the child-robot interaction has always been more difficult than in adults. Adult participants can share their opinion and experience from a study in questionnaires and self-reflection (Belpaeme et al., 2013). A questionnaire with seven questions was developed for evaluation of children's perception of NAO. Student had to mark one of the emoticons: ☺ for "yes"; 😐 for "neutral"; ☹ for "no" as an answer of a particular question.

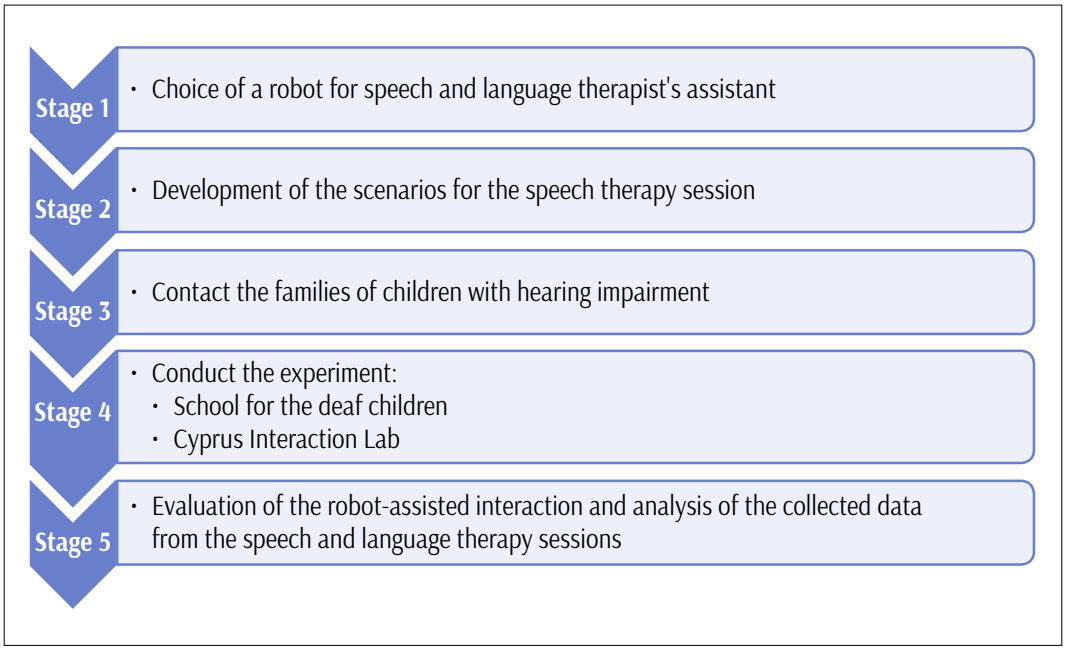

Figure 1. Stages of the experiment

Participants: Fourteen children with hearing impairment participate in the study – 7 boys and 7 girls. All of them are implanted with one or two CI. The participants are children of various ages (from five to fifteen), different levels of listening skills and language development. Seven children study at mainstream schools and the other seven – at School for the Deaf. Three children dropped off from the group for data analyses, because they had additional disabilities. There are publications with reports of lower perception scores and language development of deaf children with additional handicaps, such as mental retardation, CP, autism, blindness and various syndromes compared to children without additional disabilities (Bacciu, 2009). Six children use total communication and five students use the auditory-oral communication modality. Table 1 presents the profiles of the participants whose results are analyzed and discussed in this work. Students from the special school preferred to use sign language for communication, while children who study at the mainstream schools use verbal communication.

Table 1. Participants in the study

Case №	Age	Gender	School	Communication modality	Number of CI
C1	5	male	School for Deaf	Auditory-oral	2
C2	10	female	School for Deaf	Total communication	1
C3	10	female	School for Deaf	Total communication	1
C4	14	female	School for Deaf	Total communication	2
C5	14	male	School for Deaf	Total communication	1
C6	15	male	School for Deaf	Total communication	1
C7	15	male	School for Deaf	Total communication	1
C8	5	female	Mainstream school	Auditory-oral	1
C9	7	male	Mainstream school	Auditory-oral	1
C10	10	male	Mainstream school	Auditory-oral	1
C11	11	male	Mainstream school	Auditory-oral	1

SETTINGS

One part of the robot-assisted speech and language therapy sessions took place in the School for the Deaf in Nicosia, Cyprus. The school director gave the permission for organizing and conducting the experiment at school. The second part of the experiment took part at Cyprus Interaction Lab in Limassol. Hearing-impaired children who study at the mainstream schools were invited at the Lab to take part in the robot-assisted speech and language therapy sessions.

The sessions were performed in a quiet room. The robot NAO was placed on a desk, facing the child. Most participants from the special School for the Deaf use total communication. Sign language interpreter attended the experimental sessions at the school in case someone needed support or additional explanation with sign language. The special education teacher attended the experimental sessions at the Lab to support the children if they need help.

Development of scenarios: Every session starts with a short presentation of the robot. Then NAO and the child introduce themselves to each other. At the start of the session, the robot plays the Ling Six Sound Test in order to check and help the team to understand what the child can hear within the speech sounds spectrum. The test could help researchers quickly identify problems with the child hearing technology or changes in hearing (Estabrooks et al., 2020: 293).

Robot-assisted therapy sessions consisted of games involving series of tasks that provoke the child to listen and use verbal language. In the beginning of every game NAO rises for a standing position. He gives the instruction

"Listen!" and makes a gesture (rises its hand up next to the "ear"). If the child's respond for a particular task is correct, NAO nods positively and says "Correct!" If the child choice is wrong, the robot says, "Try again!" and shakes its head right and left.

The first game consists of recognizing different emotions from everyday life. The robot NAO asks the child, "How do I feel now?" Then it plays the sound of an emotion (e.g. crying) and it shows the respective gesture or body movement (put the hands in front of its eyes when crying). The speech and language therapist puts two pictures with illustration of emotions, one correct and one wrong, in front of the robot, right before the demonstration of an emotion. The child picks up one of the pictures with an emotion and names it.

Shapes game involves perception of sentence with explanation for shape and colour. The speech and language therapist puts two pictures with different shapes and colors in front of NAO before the robots' instruction. The child listens to NAO's instructions, after that he/she selects a picture, names it and puts it within robot's hands. Every sentence consists of two main words: for shape and for color (e.g. "Give me the shape which is round and has the color of the sun").

Shopping game consists of tasks for identification of everyday environment sounds, understanding instructions. For the first part of the game NAO is standing next to a shopping cart. The robot is playing the sound from the bathroom – brushing teeth and in the same time, he is showing the respective body movement, e.g. teeth brushing. The products in this part of the game are the toothbrush, dental floss and toothpaste. The next task of the game included referring toys to a particular category (e.g. "I will prepare a salad. Please, help me find the products. Tell me their names and put them in the shopping cart", e.g. tomato, cucumber, lettuce).

The robot-assisted therapy session finishes with positive conclusion from NAO and "delivery" of a reward. The therapist places a small shopping cart in front of the robot. NAO "catches" the cart and it starts pushing it for few steps toward the child.

Data Collection from the study. The robot-assisted speech and language sessions were video recorded and analysed. Every child filled in a questionnaire right after the end of his/her participation. The research team developed special questionnaires in order to explore the perception of the child during the interactions with the speech and language assistant – the robot NAO. Every child with hearing impairment shared with us his/ her impressions about the games played as well as their perception of NAO's voice and speech.

Results. Researchers observed the video recordings of the robot-assisted therapy sessions. We recorded the number of correct answers from the first try of the child, the number of properly selected pictures, toys, named / signed words, and times the participant sought help – verbal and/or manual from the interpreter / speech and language therapist.

Every session started with the Ling-Six Sound test (Figure 2). The results showed that 45% of the students could hear the whole range of speech sounds. Four children who used auditory-oral modality and one child who used total communication. The students who identified five Ling-sounds are 18% and 9% - four sounds. Three speech sounds are identified by 18% of the students. The child with the lowest score could identify only the sounds [a, u]. This child used total communication. The easiest speech sound for the participants was [a] and the most difficult for identification were those from the high frequencies [s, ʃ]. Without any mistakes performed children who use the auditory-oral communication modality.

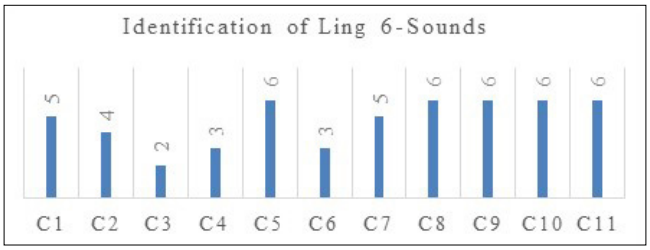

Figure 2. Results from Ling Six Sounds Test

Shape game (Figure 3) was difficult for three participants. Initially they could not understand NAO's sentences. They asked for help the sign language interpreter to repeat the instruction verbally (to do lip-reading) and manually (Figure 4). 45% of the students picked the correct picture with shape and named it correctly. Children who used the auditory-oral communication modality did not ask for additional explanation from the interpreter or the therapist.

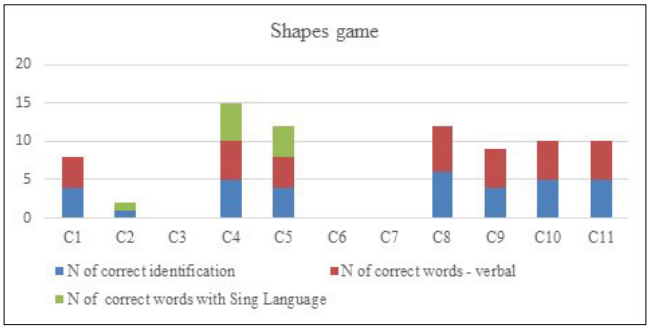

Figure 3. Results from the Shape game

Two children asked the speech and language therapist for additional explanation of 1-2 robot's instructions. Two children used combination of naming the picture verbally and signing. The participants C9, C10 and C11 did not asked for any additional help during the interaction with the robot "assistant". Children who used total communication except C5 asked for additional Sign language interpretation and verbal explanations of the instructions.

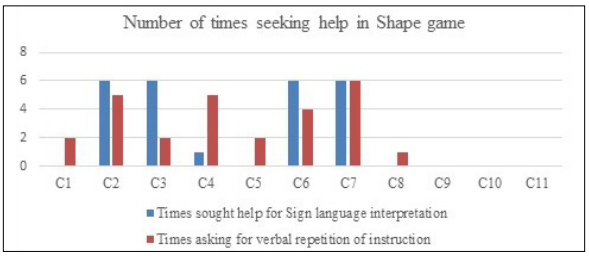

Figure 4. Asking for additional explanation of the instruction from the interpreter or speech and language therapist

The results of Emotions game are presented in Figure 5 and 6. It was about identification emotions, which NAO expressed with voice and body movements. Participant C10 passed the game without any mistakes, followed by the other students from the mainstream school. This game appeared difficult for the children, whose communication modality was total communication, and this was evident from their results and the number of times when they asked for more explanation of the instructions and Sign language interpretation.

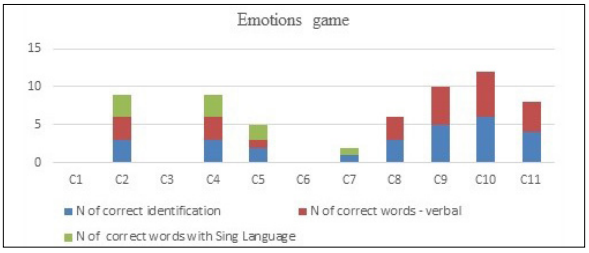

Figure 5. Results from the Emotions game and language therapist

Participants C1, C3 and C6 could not give correct answer from the first time. After the additional information from the interpreter, these children tried to answer one more time. All participants identified the "tired emotion" with yawning sound [a] and the specific gesture with covering the mouth. This was the easiest emotion for identification from the student. The two most difficult emotions appeared "angry" and "happy". It was difficult to express them only with gestures, body movements and sounds but without facial expression, (NAO has still face and cannot articulate, e.g. cannot smile).

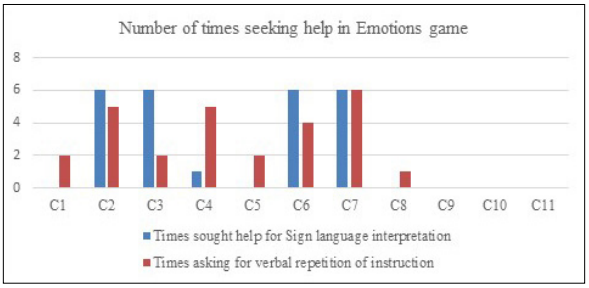

Figure 6. Asking for additional explanation of the instruction from the interpreter or speech and language therapist during the Emotions game

Shopping game (Figure 7 and 8) is the longest one. It included selection of products used in the bathroom (e.g. shampoo, soap, toothpaste, and toothbrush) and food (fruit, vegetables sugar, honey, flour). C3 could not understand the instruction pronounced from the robot and asked for sign language interpretation. This particular student had the lowest scores performance from the robot-assisted games. The professionals from the school gave information that the hearing impairment of this child was identified late and she had her implantation of CI after 3 years of age. Researchers had reported that to obtain maximum benefit from the cochlear implantation the surgery must be done at an early age with a short period after the hearing impairment establishment (Estabrooks et al., 2016).

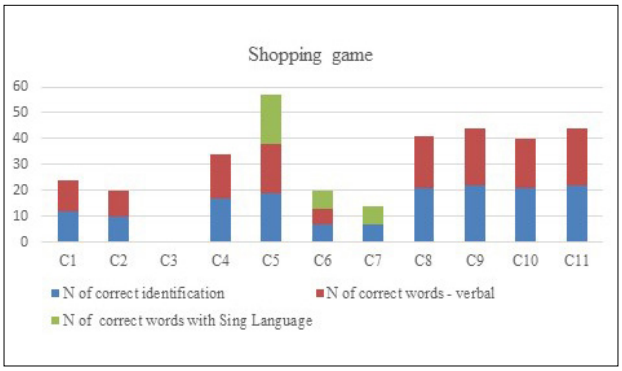

Figure 7. Results from the shopping game

The instructions during the game were less, compared to the other games of the session. Students who sought for additional help from the interpreter and the number of asking were less too as it is presented in Figure 8. C7 asked for additional verbal explanations and Sign language interpretation. C5 asked twice for verbal repetition of robot's instructions in order to use lip-reading. Three students sought for Sign language extra information. Children, whose communication modality was auditory-oral, understood NAO's instructions without any problem.

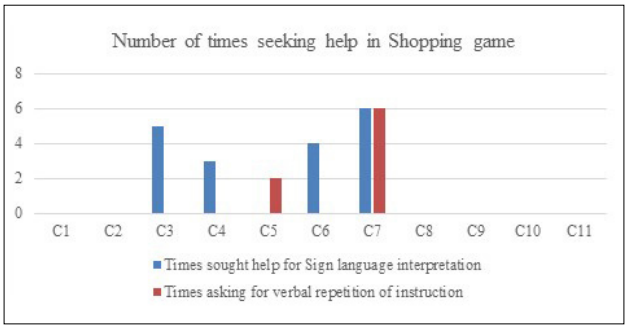

Figure 8. Asking for additional explanation of the instruction from the interpreter or speech and language therapist during the shopping game

At the end of the speech and language session, every child filled in a questionnaire. Summarized information of the results are shown in Figure 9. NAO's participation in games during the session was positively endorsed by the children. While there were some variations in the responses related to the questions about hearing and understanding the robot's speech and voice. The questionnaire also included section for additional comments. Two students made a remark that they prefer to slow down the NAO's speech rate in order to hear better its instructions and to understand them. These students were from the School of the Deaf, participants who use total communication. All participants liked the games assisted with NAO, more specifically the emotions and shopping games. Three students did not hear clearly NAO's speech. Four children reported that they did not understand the robot. There were students who made a remark for the voice of NAO.

The software of the robot gives the opportunity for modification of the voice for future studies with hearing-impaired children.

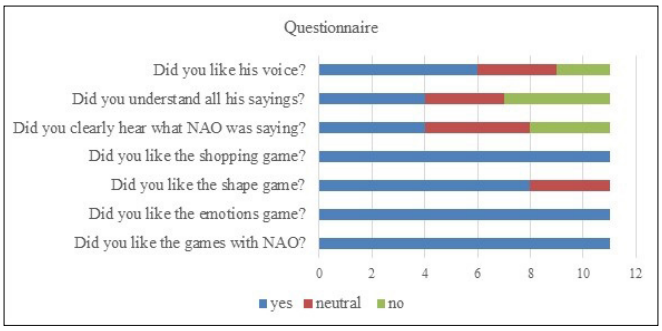

Figure 9. Results from the questionnaire for children who participated in the study

DISCUSSION

The application of NAO as an assistant in the speech and language therapy has some advantages and disadvantages. Some of the disadvantages are its price, dependence of power to work, technical support, and limited number of fingers. The robot is still expensive and it is not affordable for all people / mass consumption. It is used mostly for scientific research. The robot has a battery, which is rechargeable and with limited capacity. The therapist must charge the battery before every session. The duration of robot-assisted activities should match the battery runtime. There are some challenges when using robots. It requires technical knowledge to program the desired activities and deploy the applications on the robot. The three fingers of NAO's hand are a limiting feature. Thus, it cannot represent the all range of manual signs for Sign language.

The children who used total communication faced some difficulties with the games. They could not understand all played instructions from the robot, because they needed to use their listening skills that are obviously limited. Most of these students with hearing impairment needed additional Sign language interpretation during the activities and more supporting visual cues. To improve

interaction during games for this particular group of children who use manual communication, some improvements are needed. For example, to add more visual cues and deploying some signs on NAO, in the language the children use, following the example of Kose et al. (2011). Nevertheless, this robot has only three fingers and it is a limiting feature for signing.

The robot can be used for specific tasks. NAO cannot take complicated decisions for action or answer related to the situation of interaction with a child. It cannot replace the therapist but it can facilitate and support his / her work.

In our opinion, NAO has more advantages for assisting the speech therapy. NAO has human-like simple behavior, it moves its body (walk and dance), it listens (speech recognition), it speaks, it can participate in simple dialogue, it sees (picture, object, face recognition), it can repeat tasks many times exactly in the same way. The robot sustains children's engagement in interaction, motivates them for active participation in the therapy activities. The collected data show that the hearing-impaired children accept the robot as their friend. All participants liked the speech therapy sessions assisted with NAO. All children liked to play with it. They were excited during the interaction with the robot. Children liked to touch NAO and tried to initiate conversation with it even after the therapy sessions. When the child does not understand an instruction or robot's speech, the therapist may replay the task as many times as the situation requires. Every repetition will be the same. The robot's voice pitch, loudness and voice speed may be adjusted depending on the individual preference of the child.

The lack of articulation can be discussed as a positive and a negative feature in the same time. This could be disadvantage if the person with hearing impairment is on the stage of speech therapy that requires improving the articulation. For the purpose of presented study, lack of human mouth is a unique feature and enables the participants to use actively their listening and practice their ability to understand heard speech. We believe that NAO is a good tool to assist the speech and language therapy with hearing-impaired children.

Obviously, children whose communication modality was auditory-oral showed better scores in games that are assisted by the robot. They use verbal communication and study at mainstream schools. Those students demonstrated better listening skills compared to the others using total communication. The most difficult game for all participants was the shape game, because the robot presented all instructions verbally without any gestures. The only visual cues were the two pictures placed in front of the robot (one of them was the correct choice). Students had to look for two main words in every instruction – for the shape and for the color.

The games, designed for the current study with NAO are suitable to apply in cases of children with hearing impairment who undergo auditory-oral approach program or auditory-verbal. The unique characteristic of the robot is its inability to articulate. Thus, NAO can speak without covering its mouth

and this eliminates lip-reading in the same time, which provokes the child to use actively his/her listening skills. Our idea of robot-assisted therapy with the present design of games overlaps the recommendations of Estabrooks et al. (2016) for auditory-verbal approach. We use play strategies for "joint attention" and "turn-taking", no lip-reading and active use of listening.

CONCLUSION

The NAO's incapacity of articulation does not allowed lip-reading and therefore makes the robot a perfect assistant for stimulation and development of listening skills. The humanoid robot NAO was successfully used as assistant in the speech and language therapy sessions. Children who used mainly the Sign language for communication presented difficulties to understand the robot's instructions. During the games, these children sought help from their speech and language therapist (additional verbal explanations – for lip-reading and Sign language interpretation). NAO had limitation in deploying Sign language because it has only three fingers on its hands. However, it could imitate some body movements and natural gestures to support the interaction with the child and to look more naturally. Children with hearing impairment from the mainstream school had better results because they could hear and understand what NAO said. The results of the experiment represented limited number of participants. The research should continue in the future to examine the characteristics of this robot that would help making the robot-assisted sessions efficient and help more hearing-impaired children to develop their listening, speech and language in a playful fun way.

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