Nora - Interactive Rehabilitation Robot for Children

Summary

[Final Video - Group 17]

Carrying out physical rehabilitation therapy exercises after an injury can be repetitive, lengthy and painful for recovering children. Therefore, their motivation may quickly decrease at any stage of the exercises. In this project, Nao, a social robot, is used to address this problem. Using its gestural communication, storytelling and capabilities of playing audio. Nao aims to motivate children to perform homework exercises at home and achieve the goal of the therapy. The interaction between Nao and the child starts by initiating a bonding process. It is followed by Nao introducing and illustrating exercises as part of a storytelling experience. Exercises are performed together by Nao and the child, maintaining the child's motivation. The interaction ends after completing the exercises.

Foundation

Problem statement

Any damage to a human's body can be called an injury. Injuries can range from minor to critical, and they can occur to people of all ages. They affect children too. Some sports injuries are more common when children are growing (see growth-related disorders), other sports injuries are more dependent on the type of sport the child participates in. The chance of children suffering from a fracture in their youth is 40% for boys between 6-16 years and 28% for girls. Most fractures in children are caused by falls, with a bicycle, skateboard, trampoline or a fall from a climbing frame or bunk bed (Federatie Medisch Specialisten, 2019). This research will focus on arm injuries among children under the age of twelve.

After a fracture, there are often restrictions in movement (less good bending and stretching), and that is maintained. A fracture can be perfectly healed, and an operation can be completely successful, while the child is still not using the arm or leg properly. Many children and young people who have had an operation on the arm or have broken this arm find it scary to put full weight on it again. The muscle strength will also lag behind because it will only improve when one uses the arm or leg again. If this is the case, a pediatric physiotherapist can help to use the limb more often in the right way. Besides, the pediatric physiotherapist can help to extend and bend the arm or leg again fully. Of course, this also applies to fractures or operations on places other than legs and arms.

Most physiotherapy patients can only make it in for a single or couple of relatively short treatment sessions per week with a therapist. Because of this, a home exercises program is given to the patient, which is one of the major components of success in physiotherapy in order to make the patient move and feel better. This program is based on the physiotherapist's findings from the visit and will likely change and develop throughout the treatment.

However, rehabilitation therapy exercises can be repetitive and lengthy, requiring high motivation and adherence of the patients to achieve therapy goals. Moreover, the exercises are often painful and leading to a decrease in motivation. This causes children to skip the exercises or perform them too quickly, resulting in an incomplete arm recovery. In a meta-study analysis of 15 studies on the influence of motivation in pediatric motor rehabilitation provided evidence that children with higher motivation achieve better rehabilitation results (Meyns et al., 2018). As a physical embodiment of the technology, social robots have great potential to answer this problem. By using gestures, storytelling, music or gamification, a social robot offers a wide range of opportunities to motivate children in a more enjoyable way to perform their exercises program at home and achieve the goal of the therapy.

Problem scenario

Anouk is a 4-year old girl that broke her wrist when she fell from a climbing frame while playing with other children on the playground. Anouk's mother saw the accident happening and brought her to the hospital. Anouk was diagnosed with a broken wrist, but she did not need surgery. Instead, she just received plaster around her wrist to protect the fracture and a sling to give her arm rest. After four weeks, Anouk was allowed to take the plaster off. Because she told her mom that she still experienced some pain, she was advised to visit a physiotherapist in order to start moving the wrist and arm in a usual way again.

After the first therapy session, Anouk was given a program of arm and wrist exercises on paper to perform at home. Her mom was told to help her with performing these exercises correctly. On the first day after the physiotherapeutic session, Anouk sat down with her mom to perform the exercises. After a couple of minutes, Anouk got bored by the exercises and started to act annoyed. Instead, she wants to play a game on her tablet. Her mom tries to force her to perform the exercises but loses her patience after a couple of minutes. In hope that it will go better the next day, Anouk's mom gives up. The following day Anouk's mom wants to sit down with her daughter again to perform the daily exercises. This time Anouk does not feel like performing the exercises at all and ignores every attempt of her mom to convince her to do it. After a week, Anouk and her mom revisit the physiotherapist. With her one week of therapy done, the physical therapist concludes that not much progress has been made. They perform the exercises together again, and the physiotherapist advises Anouk and her mom that in order to strengthen and fully heal the wrist, the exercise problem should be followed. Anouk's mom is not sure if she will be able to make Anouk perform the exercises and returns home only hoping that this week will be better.

Target Audience

The direct stakeholders in this project are the injured kids like Anouk and Levi, who cannot do their daily habits and play with friends which can lead to underdevelopment in social skills if the injury takes too long. The injuries could also be a cause of not being able to do everything at school. Other direct stakeholders are the parents/caretakers of the child. The parents will have to aid in daily habits, e.g. making food, lifting things and in some cases, even putting clothes on. Last but not least, direct stakeholders are the physical therapists involved with the recovery of the injured child. If the injured children do their exercises properly, on time and at home, the goals will be achieved faster, and the therapist will have more time to help other injured children. An indirect stakeholder is the health insurance company. The faster an injured child recovers. The less time and money will be spent on that injury. Another indirect stakeholder is the physical therapists' organisation. The organisation will be able to help more children simultaneously because the actual exercises can be performed at home.

Personas

For our design, we created two different personas. The first persona is Anouk. She is motivated to rehabilitate. She listens very well to the exercises and wants to progress as quickly as possible to play outside and dance with her friends:

Anouk

User characteristics
Age: 4
Sex: female
School: primary school
Characteristics: shy, well behaved, disciplined
Feelings about robots: anxious

Goals or needs
Be able to play outside again and dance with other children

Problem
Broken radius bone

The second persona is Levi. Unlike Anouk, he has a hard time finding the motivation to do the exercises. He is too lazy to repeat these exercises enough, and will reach his goal (to be able to play games and basketball again) much later than wanted:

Levi

User characteristics
Age: 12
Sex: male
School: primary school
Characteristics: lazy, easily bored, energetic
Feelings about robots: excited

Goals or needs
Being able to play basketball and game again

Problem
Broken wrist

Human-factors knowledge

You et al. (2006) reviews the use of an educational robot for teaching English to 6 to 12-year-old Taiwanese children. It describes some specific interaction models and assesses their effects. These models are storytelling, q+a, cheerleader, acting and pronunciation leading. The main relevance of the paper to our project is concerning storytelling. Students focused more and were much more eager when listening and watching a robot perform and answering questions related to the story it performed. However, apparently the robot can become as engaging as for it to be too distracting: when the robot changed its voice for the different characters in the story, the students became too excited and paid less attention to the robot's speech.

What can also be relevant is the cheerleader interaction model. Essentially, whenever a student gave the right answer, the robot performed a little dance or cheering sound to congratulate them. This model drew more enthusiastic participation from children as usual. One factor to keep in mind for our project: in the two-week programme described in the paper, the second week showed less attentiveness from the children towards the robot than the first one, demonstrating that the novelty effect wears out over time.

Interaction Design

Design scenario

Anouk is a 4-year old girl that broke her wrist when she fell from a climbing frame while playing with other children. Just like in the problem scenario she got diagnosed with a broken wrist and visited a physiotherapist after a while. However, during this first therapy session, Anouk was introduced to a robot called Nao. During the session, the physiotherapist gave instructions to Anouk's mom on how to make use of Nao, and gave a program of arm and wrist exercises to perform together with Nao at home. After the first session, Anouk and her mom went home with Nao. Anouk was so excited about Nao that she wanted to start it up right away to perform the exercises together. Anouk's mom starts up the Nao robot, and a couple of seconds later, Anouk takes over and starts a conversation with Nao right away. After a short introduction, Nao brings Anouk into an interactive adventure to build strength and confidence to move her wrist and arm. Anouk's mom is surprised by the way that the robot motivates Anouk to perform the exercises without having to force her to do it. After 10 minutes, Nao finishes her adventure for today and tells Anouk that she can't wait to start a new adventure the next day. Anouk feels the same way and can't wait to tell her friends about her new buddy. On the first day after the physiotherapy session, Anouk asks her mom to bring the Nao robot again to start a new adventure. Anouk feels excited to talk to Nao again. After Nao is set up again, Anouk tells the robot that she wants to start a new adventure again. Nao starts performing a new adventure and Anouk performs the wrist and arm exercises according to the points in the story where she is asked to. This continues in the following days. After the first week of therapy, Anouk expresses that she already feels much more comfortable with moving her arm and wrist. The physical therapist also concludes that a lot of progress has been made. Anouk asks if she can keep the Nao robot for another week to perform the exercises. The physiotherapist agrees with her proposal and decides that she can practice her exercises one more week with Nao. With her first week of therapy done, Anouk, her mom and the physical therapist feel confident that Anouk will be able to use her healed wrist on the climbing frame with her friends in no time. The visual storyboard for this design scenario can be found in Appendix E.

Application context

Physical Environment

The physical environment should be a room in the home where the child lives. The room should be silent and uncluttered enough for the child to be able to focus on the robot interaction and the robot to be able to recognise the speech. Moreover, there should be enough space for the robot and child to carry out the rehabilitation exercises. In order for the robot to work properly, a stable WiFi connection is needed to facilitate the natural language processing by the robot. In addition a power outlet would be needed to charge the robot and the robot should be placed on a solid/sturdy surface like a large table or on the floor.

Social Environment

The caretaker of the child could be present for the interaction if the child feels more confident to interact with the robot in their presence. However, this is not crucial.

Organizational Environment

As the very aim of the project is to reduce the need of physiotherapists having to personally supervise the children, the child and their caretakers would be alone to interact with the robot. In case of technical difficulties, there should be easy to follow documentation for common issues, and a helpline available for the caretaker to contact.

Design ideas and principles

Social robot

Rehabilitation therapy exercises can be repetitive and lengthy, requiring high motivation and adherence of the patients to achieve therapy goals. Moreover, the exercises are often painful and leading to a decrease in motivation. In a meta-study analysis of 15 studies on the influence of motivation in pediatric motor rehabilitation provided evidence that children with higher motivation achieve better rehabilitation results (Meyns et al., 2018). As a physical embodiment of the technology, social robots have great potential to answer this problem. By using gestures, storytelling, music or gamification, a social robot offers a wide range of opportunities to motivate children to perform their exercises program at home and achieve the goal of the therapy.

For this project, we are using the Nao robot as the social robot of choice. The Nao robot has a physical and intuitive interface which are fundamental elements in teaching. Because of its eye-catching appearance, moderate size and humanoid behaviour, the robot is easily approachable for children (SoftBank Robotics, 2020). Moreover, Nao is fully programmable, able to speak and can respond to the environment by using its touch sensors, recognise shapes and people with its camera's and can recognise speech by using its microphone.

Another essential feature of the Nao robot is that it is able to use its body to gaze, walk, and make gestures. Because this project concerns a robot which has to motivate children to perform their physical exercise in order to recover, the use of the movements can be of great use. The Nao robot can for example use its gestures to provide an example of how the child should perform the exercise or portray the story that it is telling. All of which can help the child to motivate to perform its given exercises and have a speedy and happy recovery.

Story & Storytelling

A good story should engage the child by being interactive and should take the child's mind off having to do their prescribed exercises by integrating these naturally into the story flow. An ideal starting point for this kind of stories is children's shows with fourth-wall breaking interactions with the audience, such as Dora the explorer. Mimicking Dora's style, the robot interacts with the child through short, natural sentences, then waiting for the child's input or reaction.

Some key aspects of the story are its language, its setting, and its presentation. An appropriate story has age-appropriate language – not too complicated for the child to have difficulty in grasping but not too simple so that they get bored. The story should have varying elements to keep up the attention of the child, and these should be ideally matching the interests of the child. The robot should accompany its speech with appropriate gestures, befitting the emotion behind the sentences and the story context. The story should be shared in snippets (maximum of three-five sentences) with options for the child to pick.

Taking in the story snippet by snippet does not require that long of an attention span, and providing options increases engagement. Engaging with the story (making choices and carrying out exercises) should be rewarded by the robot.

Conversational interaction

The story that the robot will be telling is made up in such a way that the user will have to make specific movements at some points. There will be, for example, a case where the user will be able to choose to go inside or to go around(imaginary), as the robot has speech recognition. Based on the decision of the user, there will be a place to visit and an exercise to do. If the user entered the cave, there would be some boulders to lift up or reach for another obstacle if the user chose to move around. The user will have to go through all possible exercises, the decisions change the order of the exercise, and the order of the places visited. The goal is to create a “game” in which the user does not necessarily have to focus on the exercises but more on having fun.

Non-verbal behavior

The storytelling robot has non-verbal features like moving with its hands and head while not being interacted with, this gives it a human-like feeling. The robot also performs hand gestures while listening and speaking, this will help to make the story more vivid. While doing the exercises the robot will, where possible, also do them to show the user how it should be done and decide at what tempo the exercise should be done.

Personalization

The Nao robot’s language is adapted to the language of a child in primary school. So it does not contain difficult words and sentences. It is also important that the robot remembers the names and that it keeps track of where the child is in the storyline of the adventure. Because the robot has to act as a friend during this time. That is because the child cannot participate in sports or play activities with his/her friends. Besides, a fearful attitude towards the robot must be taken into account. In that case, the person will be approached calmly, and it will also try to have a sweet appearance. On the other hand, if the other person is easily bored, that child should be given more stimuli, so that the child stays focused.

Robot perception

Besides being able to recognise speech, Nao is capable of recognising other environmental stimuli and responding to them. It is able to perceive subtle stimuli like touch, and it has vision skills. In this project, its vision skills are used to recognise the face of the child before starting the conversation.

Reflection

Feedback Students Utrecht

Our idea was enjoyed by the students. One of the students mentioned that she was also doing something very similar with the kids she was teaching. An idea we received from her was to add music to the exercises. The mood board the students made was meant for three different groups, but there were some good ideas that could be used by us. The mood board was divided into four different sections. The first section was about “Movement and gestures”. This section was about using mimicking gestures to represent sound or images. Since we are planning to use sounds, we don't need gestures for this.

The second section was about “Interactivity”. Establish a relationship, so the kid will like the robot (mimic gestures, mirroring each other). Make the robot and the kid feel like they're in it together. We also had something like this in mind. Instead of the robot mimicking the kid, the kid will mimic the robot with the exercises. And the story will be told in such a way that they’re both in it. The third section was about “Space and ambience”. In this part the students told us to let the kid imagine the fantasy world that we are creating by asking him/her questions like “what do you smell?” or “what do you see?” and “what do you feel?”. By including senses, the fantasy will be more fun, and the kid will enjoy the story more.

The last section was “Narrative”. The students told us that pauses after each line is essential, this way the story would be more suspenseful. Engage the kid by creating something with materials found in the room. This, we can't use because the robot is not very stable and we don’t want to injure the injured kid again.

The demo video showed how to interact with the robot. It also showed how the robot is moving and the gestures. The feedback we got on this video was that the robot was trying too hard to be human-like, this can be fun for a four-year-old, but for a ten-year-old kid this will get boring too fast. When the robot hears a choice of the kid, there is no invitation from the robot. The robot just immediately starts with the story. Also, there was no logical structure in the story. The reason for going on a journey with the robot was not clear. In the demo video, there was no ambient sound. Ambient sound can add much to the feeling. So we have decided to give every biome a different sound when it’s entered.

Use case

Title	First Physical Therapy Session
Objective	Objective 1: To initiate the bonding process between the child and the robot. Objective 2: Stimulate exercises by a story
Actors	Child (primary user and active participant of bonding process and exercises) Robot (initiates bonding process and implements the exercises) Caretaker (introduces the robot and sets up the room)
Precondition	The room has to be set up by a caretaker. The child is escorted to a room where the robot and the room is ready.
Post Condition	The child has completed the prescribed exercises with the help of the robot. The child had fun.
Happy Flow	1. Caretaker sets up the room 2. Caretaker places the robot in a room and asks child to stand in front of the robot 3. The child stands in front of the robot 4. The robot introduces itself only after detecting a face by telling its name and its role 5. The robot asks the name and age of the child. 6. The child tells his/her name and age. 7. The robot says it has a very interesting story to tell and it starts with the introduction of the story. 8. Robot introduces the exercise as part of the story 9. The robot illustrates the exercise and counts. 10. Child carries out the exercise at the same time. 11. The robot congratulates the child when the counting is done. 12. Go back to step 8 for the second exercise and follow the next steps. After performing the third exercise, continue to step 16. 13. After completion of all three exercises for this session, the robot ends the story for today. 14. Robot expresses its hope that the child's wrist is feeling better now

Alternative Flow	For each scenario, the robot waits for the child to recognise what movements they would have to do. In case of the child's inability to recognise the correct exercise, this is the alternative flow.
	
	a1. robot gives an explicit hint.
	a2. robot imitates the correct exercise
	a3. the child tries to carry out the exercise.
	    a3-success: return to happy flow.
	    a3-failure: go to a4.
	a4. the robot introduces a saving sequence skipping the exercise
	    a4-success: return to happy flow.

Requirements and claims

		Claims	
UC Step	**Requirement**	**Upside**	**Downside**
4	Robot can introduce itself	The robot initiates the interaction, creates a bond.	The kid will be bored/is not interested.
5	The robot has the ability to recognise speech in order to recognise the users speech input	The robot can ask questions to the user and perform different actions, based on this input.	The user might get the feeling that the robot understands everything that the user says
7 + 13	The robot is able to tell a story	The child is fascinated and very interested in the story.	The child gets bored and is not interested in the story.
9	Child is doing the exercise, the robot is doing it at the same time	Robot ensures that child performs the exercise	Child can lie, no movement recognition yet
11	The robot is able to congratulate the child.	The child becomes enthusiastic about the exercises	The child does not like the congratulation.
13-16	Robot is able to talk to the child.	The child feels good because the robot is interested	The child thinks it is taking a long time.

Interaction diagram

Interaction diagram - Group 17 or see Appendix G

Implementation

Nora starts the interaction by greeting the user and asking for his/her name and age. This information is then checked with the Dialogflow entity. After mentioning the age, Nora continues the interaction by offering the user to follow two of the five exciting stories that have been implemented. If the user indicates that he/she wants to follow a different story, the robot will offer other stories. The user is then able to pick the story that he/she would like. After the story has been chosen, Nora starts telling the story. Each of the stories is divided into three parts where the child can choose between two different options. Each of these options represents a different exercise.

Thanks to Nora's ability to perform gestures, it is able to show the child how to perform exercises. After each exercise is completed, the robot congratulates the child. During a full interaction this last part is repeated for a total amount of three times, so three exercises and three stories. The interaction ends with the child feeling better after performing the exercises in a fun way.

The codebase that is implemented in the Nao robot is linked to the Google Dialogflow platform. Whenever Nora asks the user a question, its speech recognition feature recognises the user's answer and sends it to Dialogflow, where it is progressed and sent back to the code as a variable. The intent manager is the class that is used to perform the decoding of the intent coming from Dialogflow and depending on the type of intent, it takes different actions. In addition to Dialogflow, the software also makes use of other external libraries, such as VADER or MongoDB.

VADER(Hutto & Gilbert, 2014) is a lexicon and rule-based sentiment analysis tool, it is used in one of our contexts to attempt to classify the user sentiment correctly. VADER assigns scores to the potential sentiment (positive, negative, or neutral) of a given sentence. In our application, we removed the possibility of the neutral sentiment to improve the sentiment scoring of VADER, forcing it to choose between negative and positive sentiments. VADER is used when Nora is asking about the state of the injury. This allows Nora to react to a broader possibility of responses than if we would manually encode intents. However, VADER is not applicable in our other contexts as in cases of ‘yes and no’ questions it would detect any sentence with a positive sentiment as a ‘yes’ answer, and the ones with negative sentiment as a ‘no’ answer. MongoDB is a no-SQL database. For the moment, only specific data are stored in this database, such as the texts analysed by Dialogflow and the choices made by the user, but in the future, it could undoubtedly be used for more complex tasks.

Unfortunately, the social interaction cloud did not allow us to implement a movement detection function. This feature would be ideal for keeping an eye on the child's exercises and indicating when the child is not performing them. However, in order to solve this problem and to verify that the child performs the exercises in the right way we implemented a feature to take pictures. During the progress of the interaction, the software in the Nao robot takes pictures at specific times while the child is supposed to perform the exercise. These pictures are then downloaded via an sftp connection.

A demonstration of Nora and child’s interaction is shown in the following video:
https://drive.google.com/file/d/1efwaH5iaZJ3_kyosejOGY_YdMeQCtQP4/view?usp=sharing

For more detailed technical information and to see the structure of the code, please visit:
https://github.com/SIR-20-21/sir-20-21-group-17

Evaluation

Research question

An arm injury is an accident that occurs often in children. To fully recover from this trauma, it is necessary to perform daily exercises. Unfortunately there are cases where children are not motivated to practise these exercises at home because they are painful and tedious. So they skip them, or they perform them too quickly, resulting in an incomplete arm recovery. The robot helps children to perform prescribed exercises in a fun way by immersing them into an adventurous story. However, does this also result into a positive effect on the children’s motivation to perform the exercises? This is interesting because it is essential for the development of the child to recover from an injury.

Therefore, our research question is “*What is the effect of involving a social robot in physical rehabilitation on the children’s motivation to perform the prescribed homework exercises?*” Herewith, it is hypothesised that involving a storyteller robot in a physical therapy session at home increases the motivation of children. It is also hypothesised that it increases enjoyment throughout physical therapy. The research question is planned to be addressed by programming a storyteller robot which will be used by injured children during physical therapy homework sessions at home.

Method

Participants

Because of the pandemic, during this experiment, the children for which the robot is programmed will not be used. Another group of students who are also following the Socially Intelligent Robotics course at the Vrije Universiteit in Amsterdam will be our participants. The students are between 20 and 30 years old. Of these, one female and 3 are males. They all live in Amsterdam or close to Amsterdam.

Participants from the target audience are to be children between the ages of 4 and 12. This group of participants should consist of equal gender distribution. The participants would be recruited through pediatric physiotherapists and primary schools in the province of North-Holland. It should be clearly stated that they should not be familiar with the existing social robot Nao. The province of North-Holland is specifically chosen because the travel time is short compared to other provinces. This makes it easier to organize meetings. At least 20 participants are required for this experiment.

Design

The participants are divided into two groups. Both groups receive the same physical therapy exercises and instructions to follow. Participants are assessed as a group as well as individually. One group is asked to perform the exercises with the help of the storyteller robot Nora first and without the robot second. The other group is asked to perform the exercises without the help of the storyteller robot Nora first and with the robot second. The order is also taken into consideration during the assessment.

In this experimental design, the independent variable is the presence of the storyteller robot. The independent variable has the value of 'Yes' for the experiment group and the value of 'No' for the control group. The dependent variables are the motivation, interest, and the enjoyment of the participant during and after the physical therapy session, as well as the difficulty of following the exercises. It is measured through an online questionnaire that is filled by the participants.

Materials

The experiment takes place in a room on the university campus.

Table and chair

In this room, there should be a table and a chair. These are used for arm exercises that are explained in the implementation section.

Nao robot

During the experiment, a Nao Robot (a 58cm tall humanoid robot) was used. The robot had been programmed with the relevant Python libraries, Google's Dialogflow, and Softbank Robotics' Choregraphe (for the gestures). The robot's introduction and responses to the lesson content are pre-programmed.

Computer

After using the robot, an online questionnaire is completed. The link is sent after they use the robot. The questionnaire is completed on a computer.

Questionnaire and instructions paper

The questionnaire (see appendix A) is made in Google Forms, and the instructions paper (including the consent form) (see appendix B) is printed and handed over to the participants. The questionnaire is filled in immediately after the interaction with the robot. The questionnaire consists of the following parts: general information of the participant (age, gender, previous experience with physiotherapy), the user experience (how difficult they found the exercises if they had any comments, etc.) and the ranking of motivation, interest, and enjoyment on a scale of 1-5. The instructions paper contains instructions to carry out the exercises with the robot.

Set-up
See appendix C (figure 1).

Procedure

Ideal participants for this research are to be recruited in clinics of pediatric physiotherapists, and primary schools. Prior to conducting the questionnaire, the participants are told that the goal of the research is to improve the way that physical rehabilitation homework exercises are conducted. Thereafter, guardians of the participants are given a consent form where the goal of the research, procedure, privacy and contact information are described (see appendix B). Here, it is explicitly mentioned that all of the data is to be processed anonymously. Within the form, the legal guardian of the participant could eventually give permission to participate in the research. In our current procedure, the consent form is filled out by the participants themselves as they are not minors.

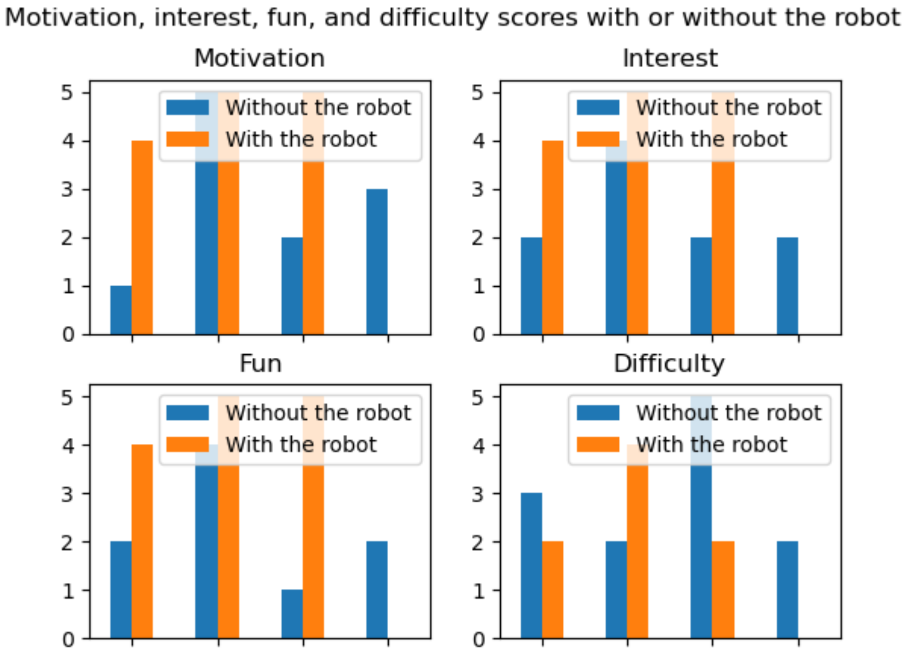
After the participant or her legal guardian gives the approval by filling in the consent form, the participant is to be put into one of the two conditions (condition with instructions and with robot, condition with instructions and without robot). In order to execute the experiment, each participant is to be individually brought into a room with a single chair and table. No one else is to be present in this room. The participants in the condition without the robot are to be given instructions about the exercises and are told to familiarise themselves with these. In the end, the instructions tell the participant to perform the exercises on their own. The participants in the condition with the robot are also given instructions about the exercises (see appendix B) and will be told to familiarise themselves with these. After this, the participants are asked to start engaging with the social robot and follow its narration and its instructions. After performing the exercises and ending the experiment, participants under either condition are to fill in the online questionnaire that is provided by a link.

Results

Due to the pandemic, it was not possible to carry out our evaluation on the intended target audience of children between the ages of 4 and 12. Our participants instead were fellow masters students following this course between the ages of 20 and 30, one female and three males. Two of our male participants had previous experience with physiotherapy.

Participant ID	Age	Gender	Previous physiotherapy	Comments
#1	20-25	Female	No	First carried out the exercises with the robot
#2	25-30	Male	Yes	Inaccurate timestamps; unclear if first carried out the exercises with or without the robot
#3	20-25	Male	Yes	First carried out the exercises without the robot
#4	25-30	Male	No	Only carried out the exercise without the robot

The participants ranked interest in the activity, motivation in carrying out the exercises, the fun they had throughout the activity, and difficulty of carrying out the exercises on a scale of 1 to 5. While it is difficult to derive any meaningful trends from such a small pool of participants, it is still useful to visualise the scores participants gave with and without the robot (see appendix D for larger graphs).



Discussion

It is important to repeat here that because of the limitations that were present due to the coronavirus, we had very few participants that participated in the research. Moreover, we were not able to conduct our research on our target audience. As a result of this, we can not make any firm conclusions about the effect of the rehabilitation robot on children. However, we were able to carry out an analysis based on the input of the 4 participants following our evaluation procedure.

The interaction with the robot was ranked higher by the participants on interest, motivation and fun than the activity without the robot. The participant who only carried out the exercises without the robot fits mostly in this trend. While it is impossible to say for sure due to the limited number of participants, the presence of the robot seems to have a positive influence on the interest in the activity, the motivation to carry out the exercises, and the fun they had while engaging in the activity. One factor to consider, however, is that the novelty of interacting with the particular programme of the robot might influence perceived interest, motivation and fun, and this effect might wear off with time. In fact, the factor of time is one of the most serious limitations of our evaluation procedure. As our target audience is expected to interact with the robot for an extended period of time (weeks or months), we might expect a decrease in the engagement with the robot. Yet this is not a factor for which we currently have the time or resources to test.

The difficulty might be our most challenging metric to assess properly. Out of our three participants working both with and without the robot, two perceived a decreased difficulty in following the exercises when interacting with the robot. The discrepancy between their scores is likely to be affected by the order in which they did the non-robot and robot activity. Participant #1 worked with the robot first, and when it came to doing the exercises on her own, she was likely already familiar with them. In her evaluation, the robot contributed only a single point of drop in difficulty. Participant #3, on the other hand, had to do the exercises on his own before working with the robot. Following the exercises based on the video and the handouts might have been a challenge. However, by the end of it, the participant might have achieved some familiarity with the exercises. This could account for the drop of three points in perceived difficulty for participant #3 when working with the robot. Participant #2, on the other hand, reported the robot activity to be slightly more challenging than the activity without the robot. The potentially distorting effects of familiarity with the exercises and the fact that one of our participants goes against the expected outcome means that further tests are required with people carrying out the exercises with and without the robot first, to assess how much the robot interaction influences perceived difficulty.

It is important to note that the results are not representative since we had no access to our target audience and that we worked with a tiny number of participants. No statistical analysis is possible to do on our results. All we can observe is some impressionistic trends.

Besides the necessary limitations of the evaluation procedure, some further design limitations need to be addressed for a final physical rehabilitation robot. First, at the moment, we have no way of monitoring whether the user carries out the exercises when the robot prompts her. An ideal physical rehabilitation robot would have a sophisticated gesture recognition module that can check whether the exercises are carried out with the right form and with the right number of repetitions. Detecting incorrect or insufficient exercises, the robot could notify the legal guardian or the physiotherapist for intervention. Creating a precise enough gesture recognition module might be possible with the tools we have at our disposal, but it is out of the scope of this design.

Second, there are issues with the physical body of the Nao robot we are employing here. As the robot is capable of detecting the pushing of buttons on its body, there would be scope for more tactile forms of interactions with it (for instance offering a congratulatory high-five to the user), would it be not for its limitation. The Nao robot is quite unstable and is relatively easy to push over. In some cases, the robot can stand up on its own, but it is more common that its programme is disrupted by its fall. Moreover, Nao's joints are rigid, with a range of motion only very crudely approximating that of a human's: it cannot even move its three fingers independently of each other. Thus the only thing that Nao is capable of is hinting at the exercises with some inaccuracy of the expected movements. This could easily result in bad form when the user tries to carry out the exercise with the robot. A robot body with more stability and flexibility, as well as a closer imitation of the human body shape could be beneficial for our use case. Even just five independently moveable finger joints would serve to improve the experience significantly..

The third set of limitations is related to the setting in which the physical rehabilitation robot would be used. The physical space around the robot and its user might be better used to create a greater degree of immersion in the stories. Better uses might be through projecting images, and using augmented reality or physical sets. However, as the robot is intended for home use, these might not be the most feasible approaches as setting up a physical location this way might be too complicated. Extensive testing with and without these tactics needs to be done to confirm whether the benefits outweigh the effort on this ground.

Another design limitation is that only a single story exists. As the idea is that the child would use the robot over a course of a couple of months, until their physical rehabilitation has reached a satisfactory level, the lack of variety could result in the child losing interest relatively quickly. More stories need to be designed, preferably ones that even reference each other or build on top of each other to enhance the immersion of the child and to evoke a sense of progression. This requires the robot to store information about the user and the choices they made throughout the adventures. It is conceivable that at the end, an application or computer program could be designed with an intuitive GUI that allows physiotherapists to build and customize stories: setting exercises, choosing audio effects and inputting their sentences.

Conclusion

We have successfully implemented our idea of involving a Nao storyteller robot in the rehabilitation exercises. We have used many different types of gestures, sound and music in our project. In order to keep user engagement high, we have included as many user interactions as possible as part of the story within the project time limit. Considering the emotional stage of the children after an accident, we have added a motivational dance to cheer up the children. We observed that involving the Nao robot in the rehabilitation exercises increased the fun and motivation of the users. As explained in detail in the Results section, the motivation and fun level of the test groups with the robot was higher than the motivation and fun level of the test groups without the robot.

In addition to the lessons learned in Discussion, we learned along the way that during the interaction, users need to position themselves at the same level as Nao. Otherwise, Nao might lose its balance and fall while trying to keep eye contact due to its face recognition ability. Another lesson we learned is that users need to wait for 1 or 2 seconds before answering Nao's questions. Otherwise, Nao may not yet be in the listening mood.

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Appendices

Appendix A: questionnaire

Group 17 Questionnaire

Thank you for participating in our survey.

The goal of this research is to improve the way that physical rehabilitation homework exercises are given to children. Because of the COVID-19 circumstances, we are not able to conduct this research on children and therefore you as students at the VU University participate in this research.

It is important to know that the social robot (Nora) in this research does NOT represent a physical therapist or therapist assistant. Nora acts as a buddy with the purpose of making the performing of the therapy exercises more fun for the child with the injury.

* Required

What is your participant id (on the instructions)? *

1	2	3	4	5	6
○	○	○	○	○	○

Is this your first time or second time performing the exercises? *

- ◯ First time
- ◯ Second time

Did you do the exercises ... *

- ◯ ... with robot ?
- ◯ ... without robot ?

How would you rate your motivation level when performing the exercises? *

	1	2	3	4	5	
Not motivated	◯	◯	◯	◯	◯	Very motivated

How would you rate your interest level when performing the exercises? *

	1	2	3	4	5	
Not interested	◯	◯	◯	◯	◯	Very interested

How would you rate how much fun you had when performing the exercises? *

	1	2	3	4	5	
No fun	○	○	○	○	○	A lot of fun

How difficult were the exercises? *

	1	2	3	4	5	
Very easy	○	○	○	○	○	Very difficult

How old are you? *

○ 20-25

○ 25-30

○ 30+

What is your gender? *

Both presented and pre-read material

- ◯ Female
- ◯ Male

Do you have any previous physical therapy experience? *

- ◯ Yes
- ◯ No

Next questions are optional, fill them in only if you have done the exercises with the robot !!

Did the robot help you to remember how to do exercises?

- ◯ Yes
- ◯ No

How was the interaction between you and the robot?

	1	2	3	4	5	
Very bad	○	○	○	○	○	Very good

Did you get any errors during the interaction with the robot?

- ○ Yes
- ○ No

Comments

Your answer

Submit

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Google Forms

Appendix B: instructions paper

Group 17 - Instructions Nora Rehabilitation Robot
Participant number:

Goal of the research:
The goal of this research is to improve the way that physical rehabilitation homework exercises are given to children. Because of the COVID-19 circumstances we are not able to conduct this research on children and therefore students at the VU University will participate in this research.

Time of research:
The total time for each participant to complete the research is 15 minutes.

Privacy, anonymity and voluntary participation:
This research collects data from the participants by taking pictures of the exercises and collecting the answers in the questionnaire. All of the data will be saved anonymously. Moreover, we are not able to trace back any of the answers to you personally. You are not obligated to take part in this research. You are not obligated to answer any of the questions that you do not want to answer. If you consent to participate in this research, you will be able to end your participation at any moment without consequences. In this case all of your data will be removed.

Contact information:

Consent:
I have read and understand the purposes of this research. I hereby consent to anonymously share the collected data with the researchers in this project.

Name participant Date

____

Signature participant

____

Context:
Imagine that you are a 12-year old child. You fell from a climbing frame while playing with your friends at the playground. After visiting the hospital you got diagnosed with a broken wrist and got plastered. After some time you and your mother visited the physical therapist to see how your wrist is doing and to start doing some exercises together. You can practise these exercises with the provided video. After the session you received homework exercises to perform at home. These exercises can be found in this document.

In this research, the participants will be split into two groups. See procedure for more details.

It is important to know that the social robot (Nora) in this research does NOT represent a physical therapist or therapist assistant. Nora acts as a buddy with the purpose of making the performing of the therapy exercises more fun for the child with the injury.

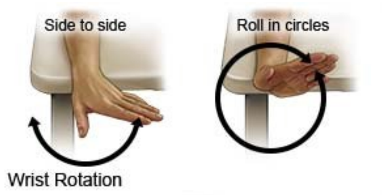
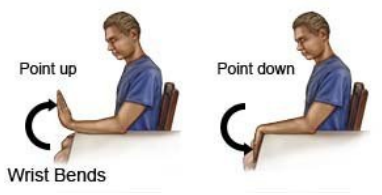
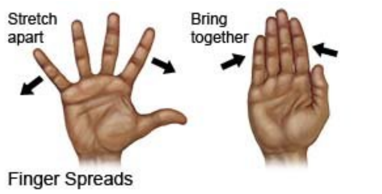
Materials:
In order to perform this research, the participants need the following materials:

- This document including the consent form, procedure and exercises
- Nao Robot
- Physical therapist session video [link]
- Online [questionnaire]

Procedure:
- Receive access to the repository of Group 17 one day before the research day and clone / install it.
- On the research day, all 6 students will watch a video together with the exercises to simulate a visit to the physical therapist. In the video, the exercises will be explained.
- After the video, the 6 students will be split up into 2 groups of 3 people.
- Group 1 will go to room 1. Group 2 will go to room 2.
- Each participant will be given this document with a participant id.
- All exercises will be done individually in the room.
- Participants in Group 1 will perform the homework exercises first without the robot.
- The participants without the robot will perform the exercises by only using the instructions on the exercise pages.
- Participants in Group 2 will perform the homework exercises first with the robot, and are also allowed to use the exercise paper.
- After both groups complete the first session, they will fill in the first questionnaire mentioning their participant id.
- Now the groups will switch rooms and perform the same exercises.
- After completing the exercises, they will fill in the second questionnaire mentioning their participant id that is on this instruction paper.

Exercises video :
https://www.youtube.com/watch?v=HJ7kdJXNdHQ
Exercises instructions:

Exercise	Explanation	Image
1. Thumb to palm stretches	1. Move your thumb and rest it across your palm. 2. Move it out to the side again. 3. Repeat 5 to 10 times.	

2. Wrist rotation	1. Move your hand from side to side. 2. Then roll your hand in circles in one direction. 3. Repeat 5 to 10 times. 4. Roll your hand in circles in the other direction. 5. Repeat 5 to 10 times.	
3. Wrist bends	1. Bend your hand back toward your wrist so that your fingers point toward the ceiling. 2. Then bend your hand down so that your fingers point toward the floor. 3. Repeat 5 to 10 times.	
4. Finger spreads	1. Open your hand and stretch the fingers as far apart as possible. 2. Bring your fingers together again. 3. Repeat 5 to 10 times.	
5. Finger to thumb touches	1. One at a time, touch each fingertip to the pad of your thumb. 2. Do this for every finger 3. Repeat 5 to 10 times.	

6. Finger bends	1. Make a tight first. 2. Then open and relax your hand 3. Repeat 5 to 10 times.	
7. Radial and ulnar deviation	1. Wrist radial and ulnar deviation is the motion of moving your wrist from side to side. 2. Hold your affected hand out in front of you, palm down. 3. Slowly bend your wrist as far as you can from side to side. Hold each position for about 6	
8. Wrist up down side stretches (radial and ulnar deviation alternative)	1. Hold your hands in front of you, palms facing to the side 2. Bend your wrist slowly as far as possible, from one side to the other. Each position should be held for six seconds. 3. Start slowly and if no pain is present, repeat 5 to 10 times.	

Appendix C

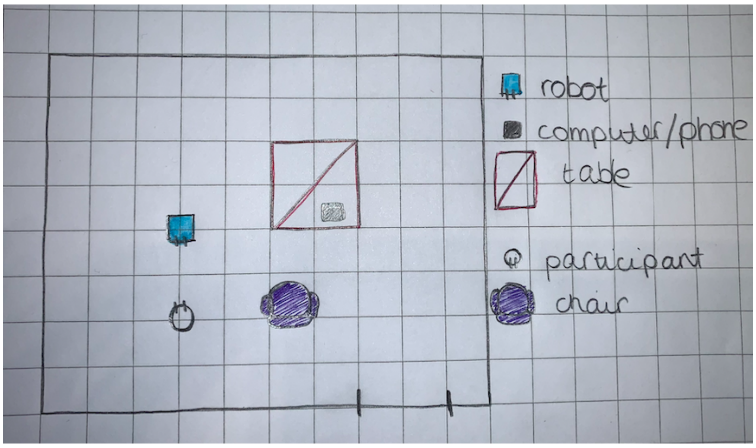
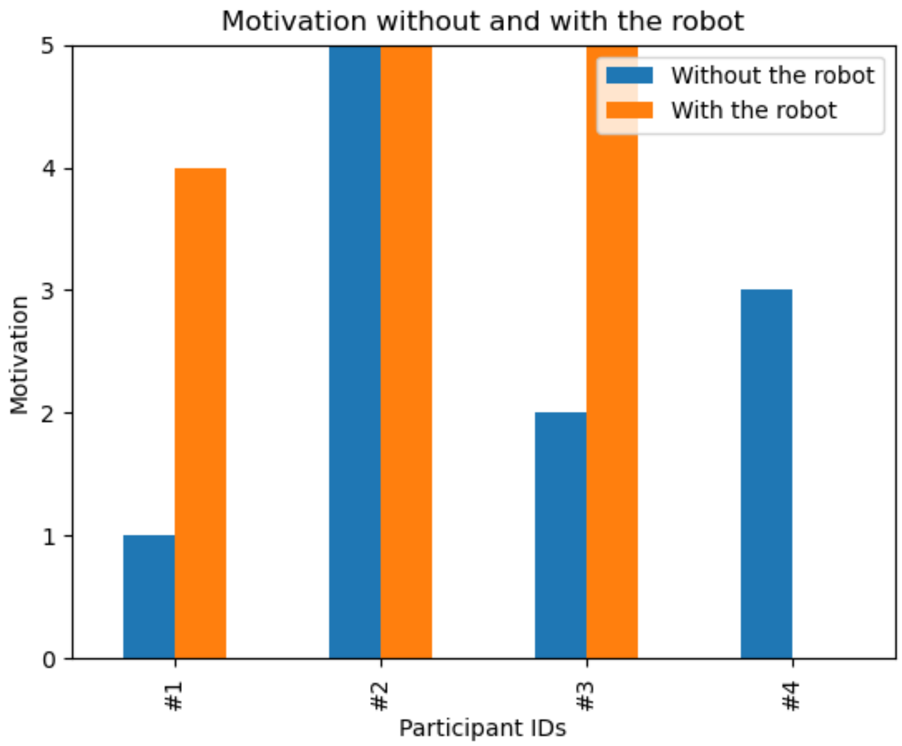
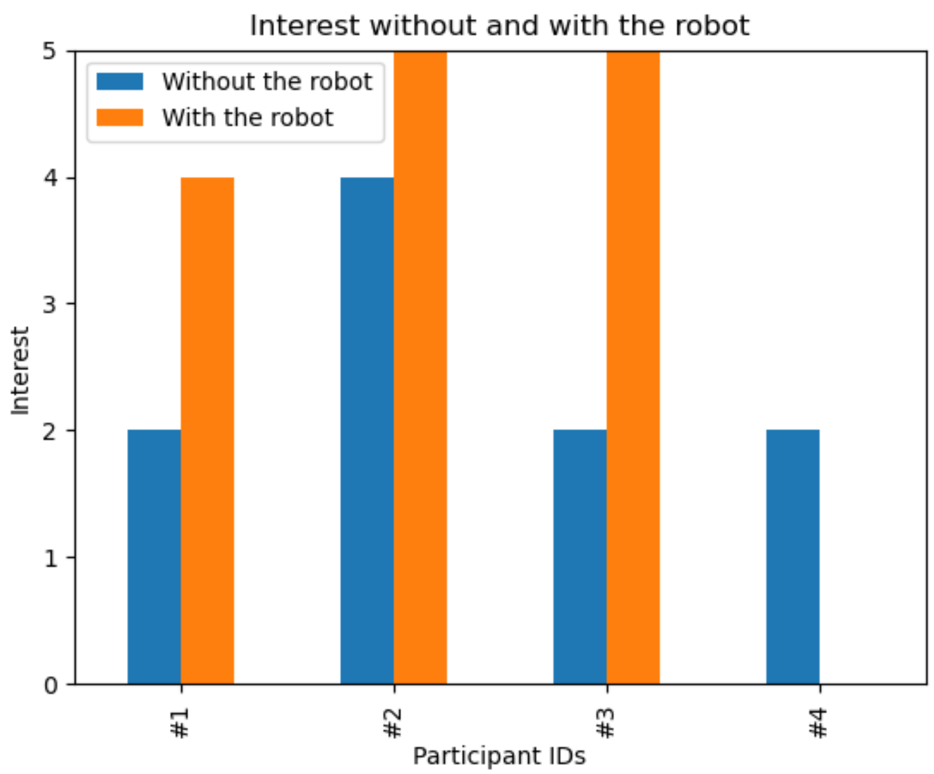
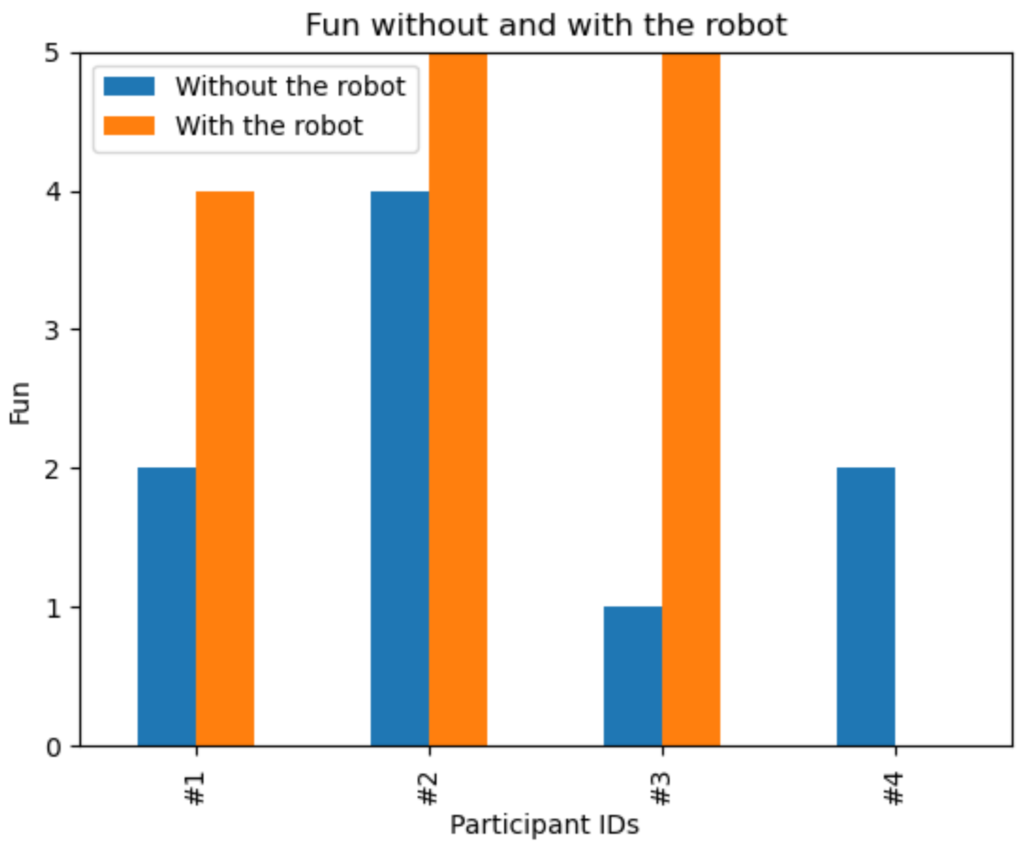


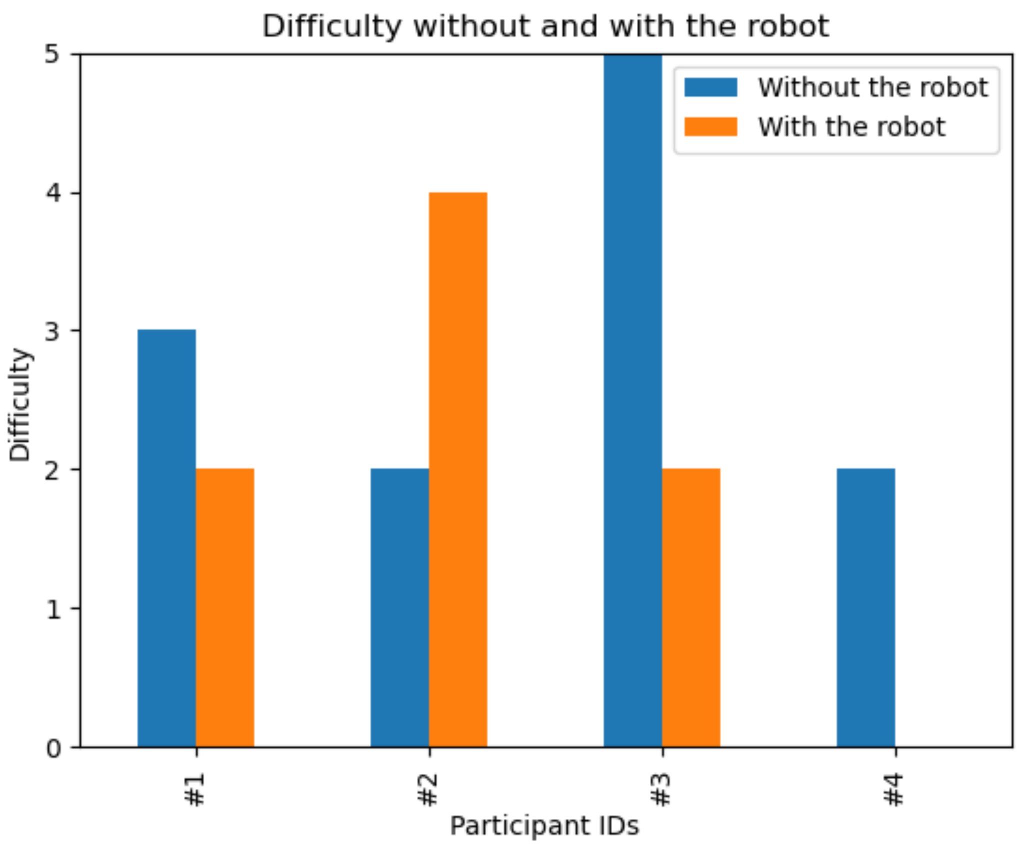
Figure 1: Room set-up.

Appendix D: Visualised results






Fun without and with the robot
Without the robot
With the robot
Fun
0
1
2
3
4
5
#1
#2
#3
#4
Participant IDs


Difficulty without and with the robot
Without the robot
With the robot
Difficulty
0
1
2
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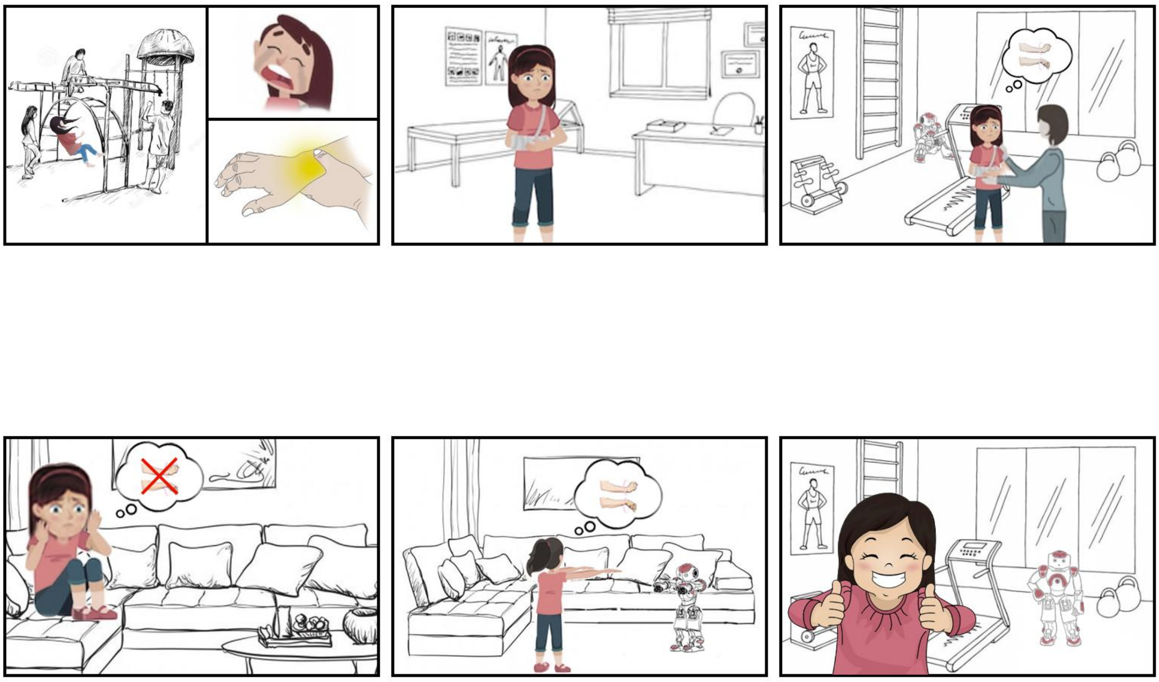
4
5
#1
#2
#3
#4
Participant IDs

Appendix E: Design scenario storyboard

Storyboard SIR - 17



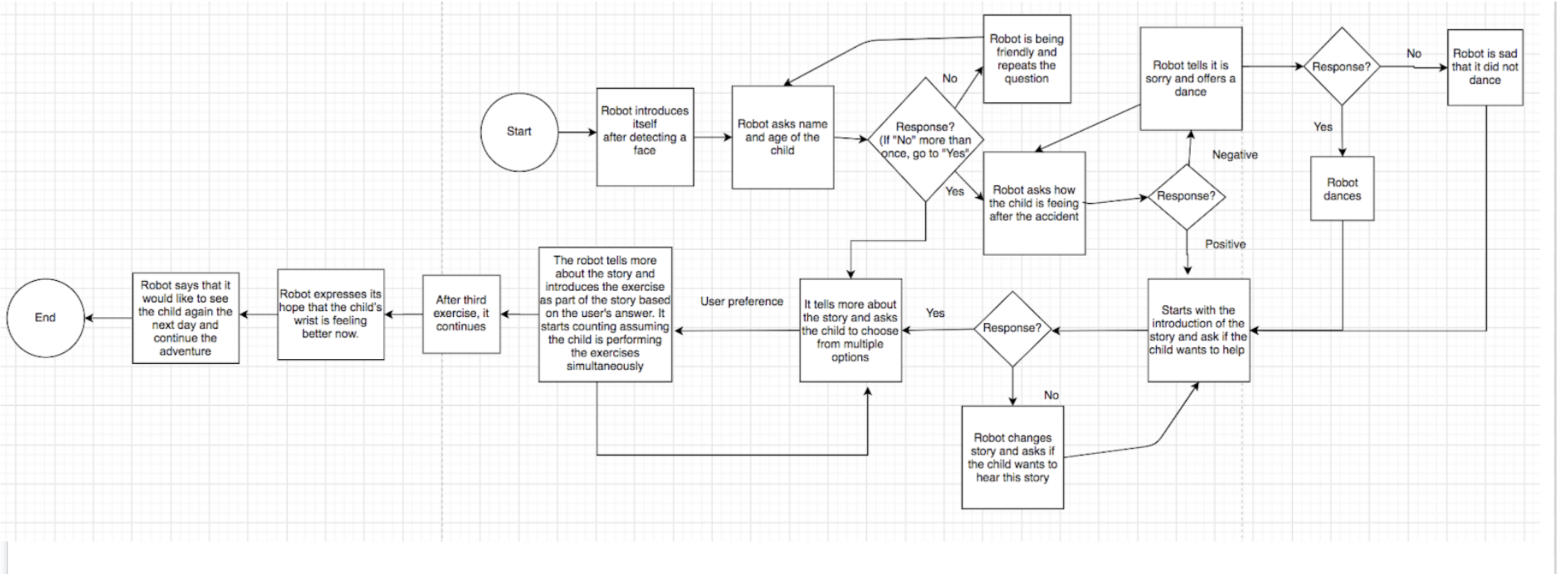
Appendix F: Summary Report Group 19

Our group analyzed group 17's Nao robot named Nora. Their idea was to have a robot to help children with their physical therapy. It would do this by helping telling them a story, the story would be interactive so asking the child questions to get them engaged. The story followed Nao, who wanted to bring a gift to their friend but had to go on an adventure to do so, at keys points in the story the child would be given a choice to either "go through the mountains" or "go through the field". After this choice a problem would occur requiring the character in the story to do a certain action such "strike the thief's with lighting" the robot would then ask the child to help do this by performing a certain gesture, such as as clench their hands into a fist and release. This would repeat several times before the story ends as the character in the story reaches its goal.

Overall we thought the idea was good but the execution was phenomenal. The story was fluid from start to finish and well told. The robot had movements throughout were coordinated with the story which really amplified the story telling feelings, the eye color even seemed to match up to segments of the story which we thought was a great touch. The interaction was also very good, in the start it was good at it asked for you name and age which made the experience feel more personal, and then the ability for us to be able to chose the direction of the story also increase's your connection to the story. The physical therapy section was seamlessly included in the story to the point where you did not even feel like it was therapy, a young child we felt that they would love this, there was adventure and the exercises seemed to help achieve the goal and not just boring exercises they would most likely not want to do.

Overall our impression was very positive, very well done not boring and made the exercises fun and not like a chore.

Appendix G: Interaction Diagram



Appendix H: Individual Project Summaries of Group Members