Article

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Long-term LEGO therapy with humanoid robot for children with ASD

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Abstract: *To utilise the knowledge gained from highly specialised domains as autism therapy to robot-based interactive training platforms, an innovative design approach is needed. We present the process of content creation and co-design of LEGO therapy for children with autism spectrum disorders performed by a humanoid robot. The co-creation takes place across the disciplines of autism therapy, and behavioural robotics, and applies methods from design and human–robot interaction, in order to connect state-of-the-art developments in these disciplines. We designed, carried out and analyzed a pilot and final experiment, in which a robot mediated LEGO therapy between pairs of children was mediated by a robot over the course of 10 to 12 sessions. The impact of the training on the children was then analysed from a clinical and human–robot interaction perspective. Our major findings are as follows: first, game-based robot scenarios in which the game continues over the sessions opened possibilities for long-term interventions using robots and led to a significant increase in social initiations during the intervention in natural settings; and second, including dyadic interactions between robot and child within triadic games with robots has positive effects on the children's engagement and on creating learning moments that comply with the chosen therapy framework.*

Keywords: LEGO therapy with robots, humanoid robots, children with ASD, participatory co-creation design, long-term interaction with a robot

1. Introduction

The challenge in building effective social and behavioural therapies with robots manifests itself in the difficulties of bridging social interaction studies, and clinical expertise to computational models that the robots are able to utilize. It has been suggested that this challenge can be resolved by therapists and trainers acting as the robot's end-users and thus creating therapy content directly (Barakova *et al.*, 2013). In order to take an important step toward achieving this goal, we searched for ways to formalise this content creation process and to facilitate the creation of meaningful and long-term training programs, which are needed for sustainable improvement of the person undertaking the therapy.

This paper discusses the content creation process in the case of training children with autism spectrum disorder (ASD) with robots. ASD are conditions where no curative treatments are available, but intensive behavioural interventions by young children during one year or longer may bring to substantial improvements.

In recent research, increasingly more attention has been given to the implementation of technology in therapy for children with autism, ranging from interactive tangibles to human-like robots (Barakova *et al.*, 2009; Kose-Bagci *et al.*, 2009; Brok & Barakova, 2010; Diehl *et al.*, 2012; Goodrich *et al.*, 2012; Huskens *et al.*, 2013). These studies show positive results from the use of robots and other interactive technologies in training sessions with children with ASD (Diehl *et al.*, 2012; Cabibihan, Javed, Ang Jr, & Aljunied, 2013; Huskens *et al.*, 2013; Porayska-Pomsta *et al.*, 2013). Although there has been a large increase in the number of research projects that aim to develop therapies for autism, most of the studies involving robots remain exploratory and have methodological flauws as pointed out by several authors, for example, Kasari and Lawton (2010), Diehl *et al.* (2012), and Huskens *et al.* (2013). Kasari and Lawton (2010) reviewed general developments in technology for autistic children and concluded that higher quality study design would improve confidence in these findings.

Diehl and colleagues (Diehl *et al.*, 2012) reviewed state of the art applications of robots in interventions for children with ASD and made a similar conclusion: although the results of these studies are promising, most of them are only exploratory and have methodological limitations. They proposed that empirical methods, such as Applied Behavioral analysis (ABA), could counter this problem. As a result, experiments that followed a carefully prepared experimental design appeared (Diehl *et al.*, 2013; Huskens *et al.*, 2013; Pop *et al.*, 2013).

Human-robot interaction (HRI) and design domains have created effective approaches for bridging the conceptual gaps between disciplines, and in this way have also helped innovation to emerge in traditionally-shaped scientific areas.

We propose a design-based approach to combine the powers of both: well-defined experimental practices in the domain of autism therapy and state of the art of behavioural robotics. We argue that the innovation-promoting methods used in the design community will result in more advancement than by letting robot programmers work with clinical experts directly.

Previously, guidelines of how to design training scenarios with robots have been proposed by Baker, 2000, Kahn *et al.* 2008, Robins *et al.* (2008), Giullian *et al.* (2010), and Gillesen *et al.* (2011). Robins and colleagues (Robins *et al.,* 2008) created an overview of existing works, that developed robot-based training scenarios and came up with a conceptual scheme that outlines the process of scenario development for robot-assisted play. Gillesen and colleagues (Gillesen *et al.,* 2011) discussed the procedural steps for scenario processing, and then implemented these into a clinical setting, and how detailed parts of a scenario can be developed. The difficulties that arise when combining the clinical and HRI research practices have been previously discussed by Kim and colleagues (Kim *et al.,* 2012). This paper gives an open suggestion ‘ that roboticists can overcome these collaborative difficulties through close partnerships and clear lines of dialogue with clinical experts’. We believe that designing not only the experiments but also the process of knowledge transfer between the domains will bring about an efficient and structured collaboration as well as results that comply with the standards of both communities. The current paper presents the second of the series of three experiments that aim to establish such a process.

In a previous experiment (Huskens *et al.,* 2013), we adapted straightforward ABA training with elements of pivotal response training (PRT) (Koegel *et al.,* 1999; Koegel *et al.,* 2001) to a training involving robots. In the current study, different from Diehl *et al.* (2013) and Huskens *et al.* (2013), we used a co-creation process that from the very beginning combined the procedures and principles of established autism therapies with design and HRI methods to create more engaging and long-term training.

This paper is organised as follows. Section 2 discusses the specific participatory co-design process ranging from the experimental design to the analysis of the user tests from two different perspectives. Section 3 shows the results from the pilot experiment which are analysed in Section 4. Section 5 proposes a methodology for redesign and Sections 6 and 7 offer a discussion and conclusions.

2. Experimental co-design

2.1. Background

It has been shown that children with ASD can benefit from training sessions that focus on specific learning goals. Game-based sessions in particular have been shown to be beneficial in training social skills (LeGoff, 2004; Kozima *et al.,* 2005; Robins *et al.,* 2008; Barakova *et al.,* 2009; Kose-Bagci *et al.,* 2009; Brok & Barakova, 2010; Porayska-Pomsta *et al.,* 2013). The use of LEGO during therapy sessions with children with ASD has had an especially positive effect. In a study conducted by LeGoff (LeGoff, 2004), in which pairs of children played with LEGO, resulted in a significant increase in the number of social interactions. Owens and colleagues (Owens *et al.,* 2008) further developed LEGO® therapy on the basis of the experiments made by LeGoff and conducted in a comparative study with the Social Use of Language Program and a control group of children who did not received specific intervention. An evaluation of social skills interventions for 6–11-year-olds with high-functioning autism and Asperger Syndrome showed that the LEGO therapy group improved more than the other two groups of children on autism-specific social interaction scores (Gilliam Autism Rating Scale) (Owens *et al.,* 2008). Other researchers (Barakova *et al.,* 2009; Brok & Barakova, 2010) have shown in several studies that interactive LEGO-like i-blocks caused an increase in collaborative play and turn taking instances by children with ASD, and that large variety of games that appeal to these children can be created with this generic platform.

2.2. Experimental design

The main aim of the current experiment is to find an effective translation of LEGO therapy to playful robot-mediated training by utilizing on user-centred game design.

In the study conducted by LeGoff, children played in couples with LEGO (LeGoff, 2004). The followed experiment by Owens and colleagues of LEGO therapy (Owens *et al.,* 2008) aimed to motivate children to work together by building in small groups. A typical project involved building a LEGO creation in groups of three, dividing the task into different roles. One child acted as an engineer (discribing the instructions), one as a supplier (finding the correct pieces), and the other as the builder (putting the pieces together). We adapted this training model to include four subjects with similar respective roles. First, the robot took on the role of supplier. We designed its behaviour in such a way that it would also serve as a social mediator (task giver/hint provider, and so that it would sometimes hide a block in order to prompt the children to ask for it. The robot was assisted by the therapist (experimenter), in case it needed to execute behaviour, that was too challenging for it to perform, such as responding to natural language cues, or providing some LEGO blocks. The therapist (experimenter) is referred to as robot Assistant. The third subject is player 1 (child with autism) who has the role of Guide (resembling the role of engineer in Owen’s experimental design). Finally, player 2 (another child with autism) has the role of Builder, and has the same role as the Builder in the Owens experiment.

During the game, the robot is used to encourage the children with ASD to engage in collaborative play and to create situations in which the children can engage in social initiations. A LEGO game that takes place between two children and a robot was developed, which extended through five intervention sessions. The children were required to develop parts of a construction during each session. During the first intervention session, two LEGO constructions (i.e., a tree and a mill) had to be built. Both constructions could be built within 10 min each. Intervention sessions two to five involved two different LEGO constructions (i.e., a motorbike and a house). A comparable pilot study showed that these LEGO constructions could be built within two sessions each.

For the different building sessions, series of scenarios were developed. These scenarios consisted of defining the flow of interaction between the robot and the two children. A very laborious part of this process was designing and implementing the robot's interactive behaviour. The children from each pair and the robot each have their individual roles in completing the task defined for that session. Each task, for instance the task of building a house, prompted the children to interact during play in the following ways:

1. The children must take turns whilst exchanging LEGO blocks,
2. The children need to make social initiations such as asking the robot or the other child a question with social meaning,
3. The children are expected to respond to such questions,
4. The children are required to ask the robot for the missing LEGO blocks.

The children were given an instruction sheet describing the steps needed to build a structure, but no information about what structure they would be building. The reason for this choice was that we hoped to increase the children's curiosity and engagement. The robot than provided prompts whenever appropriate throughout the sessions by asking the following: "Can you guess what we are building today?" If the child needed a missing block (and states so), the robot would prompt him/her to ask for it. Along with other robot behaviour, this created opportunities for the children to learn communication, and collaboration between the children.

The study used the NAO robot from Aldebaran Robotics. This robot has a humanoid appearance and movement, and its simple face and lighed eyes can show some expressions through light change and head movements. The robot is equipped with two cameras, microphones, speakers and touch sensors.

2.3. *Experimental procedure*

As can be seen in Figure 1, the study is made out of four parts (1) introduction of the robot; (2) baseline; (3) intervention; and (4) post-intervention.

The children participated in the experiment in pairs, which remained the same for each session. Introducing the robot to the children prior to the study was added as a first step to the experiment, because robots are very unusual and exciting training objects. As can be seen from Figure 1, multiple baseline design across pairs was performed. The multiple baseline design across pairs was used to investigate the effectiveness of a brief robot-mediated intervention based on LEGO therapy on the collaborative behaviours between two children with ASD during play sessions. By using a multiple baseline design across at least three pairs, the results were controlled for alternative explanations such as maturation and history (Horner *et al.,* 2005). The baseline consisted of three, four or five sessions. The intervention consisted of five sessions, and the post-intervention consisted of another three sessions. A digital video camera was used to record all sessions. This camera was placed in the corner of the rooms.

All the intervention sessions started by introducing the rules for play by the robot. During the entire intervention session, the robot was present and was leading the session. A therapist (the robot's helper in the interaction scenario) was present at each session to assist to the robot. In addition, the therapist would control the robot when a child's answer would result in more than one possible action for the robot. The therapist could see what the robot was saying and which options for continuing the scenario were available after each answer on the screen of a notebook. The therapist's action was needed in case the child gave different answers than expected. The rest of the time, the robot acted autonomously. The notebook was on at the table next to the robot. During the first session, in addition to the rules for play (which defined the norms of behaviour for the children, such as "build things together", "use indoor voices" and "be polite"), the robot also introduced the game's rules and divided the roles of Builder and Guide (equivalent to the architect in the LEGO therapy proposed by Owens *et al.*, 2008)). The Builder was given the LEGO blocks, and the Guide was given the guidelines for building

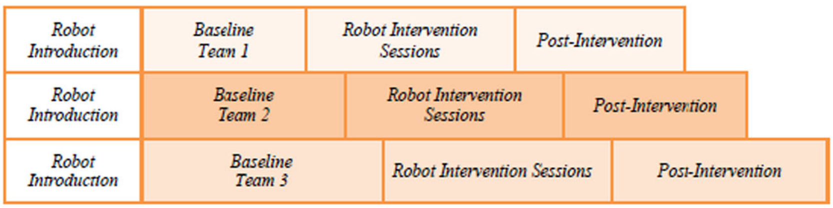

Figure 1: *Experimental procedure.*

the object. In the interaction scenarios were situations where LEGO blocks were missing and the task could not be finished correctly without them. In these cases, the children needed to ask the robot for the missing LEGO blocks, which is an additional learning opportunity introduced into the original LEGO therapy design.

The post-intervention sessions were set up in the same way as the baseline sessions, and thus the robot was not present.

2.3. Participants

The participants were six boys ages 8 to 12 years with diagnosed autism spectrum disorders according to the DSM-IV TR (American Psychiatric Association, 2000) criteria. They were divided into groups of two. All of the children were attending a day treatment or clinical treatment facility of the center for children with ASD called Dr. Leo Kannerhuis. The anonymous information about ages of the children and their score on the Social Communication Questionnaire (Rutter *et al.,* 2003), Dutch translation (Warreyn *et al.,* 2004) is described in Table 1.

Each pair of children took part in all 30-min training sessions. The video recordings of all sessions were divided in 10 s intervals. The recorded video footage of the training sessions was observed by two groups of two observers each. For the HRI analysis, which aimed to improve the robot's involvement in the interaction with the children, we employed observers that not necessarily have clinical experience. Another two observers (with clinical background) were employed for the analysis that aims to establish the effect of the overall robot therapy on the children.

A standardised setup was chosen for the experiment. However, the experiment was conducted at two different rooms (which were at different locations where the children normally stay). Each pair was always in the same room for all sessions. Both rooms had their own standardised setup, due to limitations in space in each room. The therapist was sitting in different positions relative to the position of the children, as shown in Figure 2.

2.4. Observation protocol and data analysis

The recorded experiments were analysed by both clinical and HRI-trained observers.

The analysis took place in several steps.

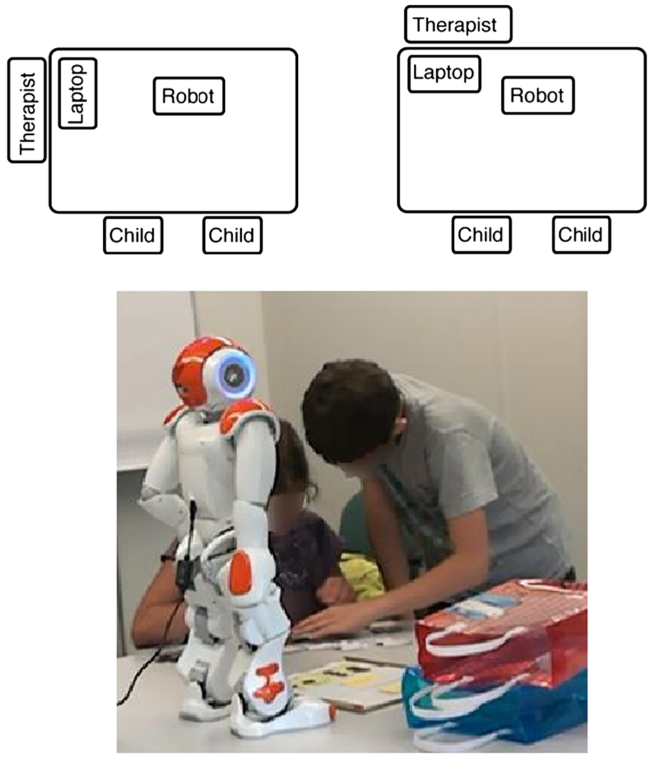

Figure 2: *Above: top view of the positions of children, robot, therapist and laptop. Below: a snapshot of a LEGO building session.*

1. By comparing the behaviour of the children during the baseline and post-intervention, we aimed to make conclusions about the lasting effect the training had on the children.
2. The behaviour of the children during the baseline and the intervention with the robot was compared to see the impact of the robot on the immediate behaviour of the children.
3. The children's reactions to the robot's prompting and to the overall behaviour of the robot during the intervention was analysed in order to optimise the robot's behavior and interaction flow.

The detailed analysis of the effect the training had on the children from a clinical perspective will be given in a separate paper. In this paper, we focus on therapy content creation, and so the observation analysis with respect to the HRI is featured.

Table 1: *Anonymous personal information children*

Child	Gender	Age (years)	Diagnose	SCQ
1.1	Boy	11	Autism; transient tic disorder	13
1.2	Boy	8	Autism	27
2.1	Boy	9	Autism	32
2.2	Boy	12	PDD-NOS	18
3.1	Boy	12	PDD-NOS subtype MCDD; ADHD combined type	18
3.2	Boy	10	PDD-NOS subtype MCDD	34

SCQ, Social Communication Questionnaire.
Score on the SCQ > 15 is an indication for autism spectrum disorders.

For the HRI study, videos of only the intervention phase were observed, because the HRI analysis aims to provide knowledge of the immediate effect of the robot on the children and of how the interactions with the robot should be built and optimised. It the clinical analysis, all the sessions were observed.

While the clinical analysis aims to provide a quantitative analysis on the occurrences of different behaviours by the children, the HRI analysis is qualitative and aims to identify the behaviours that are related to or caused by interaction with the robot. Therefore, the impression of the context and the sequence of the events are important for this analysis. For that reason the video material was presented to the observers in a chronological order. Differently, in the observations carried out for the purposes of the clinical research, the videos from the different parts of the experiment were presented to the observers in a random order, and the occurrences of certain behaviours were counted. Both analyses used the same video material, which was divided at the same temporal intervals. The videos for each pair of children was viewed once and observed by two observers for both studies.

During both viewings, the video was stopped to note the observations on paper forms that were provided to each observer. For the HRI study, the observation consisted out of three different parts. These parts consist of several steps of the interaction scenario. These are listed in Tables 2 and 3. *Part 1* consisted of an observation of the section of the videos before the actual play takes place. This first part included seven different episodes, with respect to the behaviour of the robot:

Consequently, *Part 2* involved observations of the video footage of the actual play. The observations began at step 6 of the interaction scenario and stopped at the end of the play session, which included the following steps:

Steps 6 and 7 were repeated so the observers understood the context of the observed events. This observation was less precise because the children were focused on building most of that time. Only the moments when the robot took an active role were noted. After the observation of both *Part 1* and *Part 2*, each observer reported a short impression, which included information about the children, the therapist, the robot and the atmosphere during the session.

Table 4 shows the framing of the observation protocol which consist of three columns that categorize the observations of the behaviour of each pair of children in response to the robot behaviour. The first column describes the robot's behaviour and utterances and is provided to the observers. In the other two columns, the observer fills in information about the children's reaction to the robot's particular movement or utterance. This information records the children's movement, gaze and utterances and to whom they are directed (i.e. therapist, other child or the robot) as perceived by the observers.

All data per pair was ordered in a chronological order and was than read to create an overview of the collected items. In next step of the analysis the data was then coded, and all data with the same meaning was labelled with the same code. Finally, the different codes where categorised and linked together.

Table 2: *Observation part 1: steps in the game scenario that took place during the first part of the scenario*

Step 1	Introduction
Step 2	Robot asks for the play rules
Step 3	Robot repeats play rules (optional)
Step 4	Robot asks for the game rules
Step 5	Robot repeats game rules (optional)
Step 6	Robot divides roles
Step 7	Children take cards from the robot (optional)

Figure 1: episodes observed during the first part of each session

Table 3: *Observation part 2: steps in the game scenario that took place during the second part of the scenario*

Step 6	Robot divides roles
Step 7	Children take cards from the robot (optional)
Step 8	Building the LEGO construction for the particular day

Figure 2: episodes observed during the second part of each session.

3. Results

3.1. *Qualitative analysis of the robot–child interaction*

The behaviors the robot used during the sessions can be described as speaking, standing, sitting, moving its arms to give a bag with LEGO parts, moving its arms and posture and slightly turning its head to add more expressiveness to its speech.

During each session, the robot asked the children whether they remember the play and game rules. If they could repeat the rules, the robot moved on to the next step. If the children could not repeat the rules, the robot would restate them. A repeatedly noted observation was that the robot had a slow speaking pace, and that the children did not like this. Children referred to this fact several times in their statements during the training sessions. In addition, the children stated that the robot had a strange accent. Note, that for this pilot experiment, the NAO robot could only use the Flemish language, which has a different sound compared with the Dutch language and that the experiments took place in the Netherlands, where the spoken language is Dutch. In addition, the robot pronounced some words incorrectly, because of imperfections in the computer-generated voice. These weaknesses, in combination with the repetition of the rules in every session, were incentive for the children to react negatively. Table 5 indicates some common

Table 4: *Observation protocol form*

Robot	Child 1	Child 2
Movements Speech utterance	Movements Gaze direction Speech utterance	Movements Gaze direction Speech utterance

Table 5: *Negative phrases used by the children related to the robot speaking speed or pronunciation*

Phrases used by the children	Occasion of use
Guds? (Wrong pronunciation of guide)	P1, S1, C1
Do we really need to do that?	P1, S3, C2
Do we really need to do that?	P1, S2, C1
Jaungens? (Wrong pronunciation for boys)	P1, S3, C2
Do you need to load?	P2, S1, C2
(Do you know the game rules?) Yeeheeeees	P2, S3, C2
You are speaking double	P3, S2, C1, C2
Yes we knohoow	P3, S3, C2
Nooohooo you need to read them	P3, S3, C1
Is your hard disk that small you cannot remember the rules?	P3, S3, C1
No, not these stupid rules again	P3, S4, C2

P, pair; S, session; C,child.

statements the children had in relation to the robot's pronunciation, and the repetition of the rules.

The children each reacted differently to the robot. One example of a positive attitude is one of the children making a present for the robot. In another example one of the children asked the question: 'Robot, what was your name again?' The data showes that all the children tried to touch the robot several times, and one child tried to turn the robot in his own direction. Special positive interest was provoked when the robot unintentionally fell. One child reacted by explaining that the robot fell down because it was is still a bit tired. The second child reacted by asking the robot, 'Why you are doing that?'. Some statements showed a negative attitude. For instance, one child asked a few times if he could demolish the robot or shut it off. One child also said 'I hate you robot', in combination with movements suggestive of fighting. The largest number of negative statements was related to the fact that the robot would repeat the rules of play and the rules of behaviour.

When the robot divided the task of Builder and Guide between the children, they were sometimes visibly unhappy with the division, because the role of the Builder was preferred. However, they did not discuss this preference when the robot was distributing the roles and did accepted their role.

It was clearly visible that if the robot was only speaking, the attention paid to the robot was decreased during the sessions. However, when the robot was standing up or performing another (gestural) movement, the children looked at it more even if they had seen these movements before or they did not need to physically interact with the robot by taking LEGO blocks.

The children looked towards the robot less often after they received their task and/or LEGO blocks. The children focussed all their attention on the robot again during moments when the robot provided them a bag with new LEGO blocks in order for them to continue the construction or when there was an intentionally missing block. While the children did not look at the robot while they were playing with the LEGO, it was obvious from their nonverbal behaviour that they did hear and understand what the robot said. In some sessions, the children did not manage to finish the task. When this happened, they asked for permission to finish their work.

3.2. Quantitative results

In this paper, only a general summary of the training's outcomes will be given. The same notation as in Table 5 is used: P stands for pair; S, session; and C, child.

The first child from pair 1 gave significantly more adequate verbal responses to a question from child two from the same pair ($p = 0.03$) during robot intervention compared with baseline. The same child showed significant increase of statements ($p = 0.03$) during robot intervention compared with baseline.

The second child from pair 1 showed a significant increase in the statements directed to child 1.1 ($p = 0.03$) during robot intervention compared with baseline. The same child gave significantly increased attention to the other child ($p = 0.03$) during robot intervention compared with baseline The first child from pair 3 showed significant decrease in undirected statements ($p = 0.05$) during robot intervention compared with baseline. All children showed significantly decreased instances of playing alone during robot intervention compared with baseline (combined):

1.00 effect size, sd 0.17 90% $C = -1.29 - 0.71$. All gains were lost in the post-intervention when the robot was no longer present.

For this analysis, we defined the combined cooperative play as asking related questions, making adequate verbal responses, adequate statements directed to the other child, adequate nonverbal responses, paying attention to the other child and playing together. Child 2 from pair 1 showed significantly increased cooperative play with child 1 from pair 1 ($p = 0.03$).

4. Lessons learned for redesign of robot interaction

The analysis showed that the children preferred the personal attention provided by the robot:

1. Children tried to turn the robot in a front-facing direction in relation to their body;
2. Children liked the robot's compliments and motivational phrases;
3. Children tried to touch the robot;
4. Children made presents for the robot;
5. Children called the robot by its name;
6. Children asked whether the robot would be present during the next building session or whether it was going away after the current session.

During the interviews with the therapists, we found out that for future experiments, they would prefer a one-to-one setting of interaction between robot and child. The main reason for this was as follows. If the robot is to perform as a mediator, it should be able to adapt to situations that occur between two children. It is much more difficult to foresee all the possible situations that could happen during triadic interaction than during dyadic interaction.

During unforeseen situations, the trainer (therapist) had to assist the robot with problems it could not solve for the children by itself. In scenarios where the robot is teaching a child different skills or behaviours, we need to reduce unforeseen situations to a minimum. This can be carried out either by enhancing the intelligence of the robot or by designing the interactions in such a way as to have as few surprises are possible. Dyadic interaction is thus a useful design guideline.

The nonverbal behaviour of the robot attracted the children's attention, but they did not react to it strongly even in cases where the robot made obvious mistakes. The robot's speech, however, provoked multiple reactions. The children reacted verbally to the rate of the robot's speech and, some inaccuracies in pronunciation were obviously noticed by the children, prompting critical remarks from the children. The need to prioritize the improvement of dialogue over nonverbal behaviour is a clear outcome of the analysis.

In the previous study (Huskens *et al.*, 2013), we used a pre-recorded female voice to simulate the robot speech, which was very well accepted by the children. Such a method, however, is very time consuming and costly, since changes in the dialogue cannot be made easily.

While the children clearly appreciated the robot very much, at moments they asked for help from the therapist, especially when the robot was not able to answer open questions from the children. The advantage of the robot in the sessions was that the robot attracted the attention of the children to the therapy, the children accepted the game roles assigned by the robot without discussion, although some roles (the architect role for instance) was not preferred.

Children with autism are known to focus on one item at the time. When a human is speaking whilst moving his hands, the hands movements are likely to be more engaging for the children, which results in missing the spoken message. This can be the case with the robot, too, although the observers concluded that the children are paying more attention to the robot when it moves.

The recommendations from therapists and parents, however, were to reduce the movements when the robot is speaking. The observations showed that when the robot is only speaking, the attention to the robot was decreasing during the sessions. The reason for that could be the content of the speech—the robot was giving instructions for good behaviour during the game. However, it is necessary to get more clarity about the effect of simultaneous moving and speaking on the attention of the children.

5. Redesign of the experiment

The redesign of the pilot experiment aims to bring to an improved final user test from the perspective of all co-creators. The recommendations by the therapists had a priority over the findings of the HRI analysis if these two were conflicting.

The therapists provided flowcharts of the updated robot behaviour that contained optimised sentences (length and expression), improved pronunciation and reduced amount of movement during speech. The suggestions made by the HRI experts as a result of the analysis of the pilot test that were accepted by the therapists were also implemented. All the changes that were made for the final experiment can be grouped as follows.

5.1. Removing procedural mistakes

The analysis of the pilot test showed that in nine out of 12 sessions during the pilot experiment mistakes were made in procedural steps, which can be described as follows: (1) different or wrong pronunciation by the robot (also due to the Flemish instead of Dutch text to speech (TTS) translation) this mistake was detected four times during the sessions; (2) once the assistant pushed the wrong button, which caused the robot to execute unexpected behaviour, (3) the robot fell over unexpectedly due to overheating of the motors; (4) once LEGO blocks were missing, which was not planned; and (5) in some behaviours, the movement and sound were not properly synchronised due to the limitations of the programming tool Choreographe used for the Pilot experiment two times.

On the time scale of 30 min per session, these mistakes were not so many to influence the outcome of the experiment. However, some large failures such as falling of the robot greatly influenced the children and their behaviour. For instance, one child panicked after the robot fell. Another child showed empathy and explained the robots 'mistake' presuming that the robot is still a bit tired. In the redesign phase, all these mistakes were eliminated, by reprogramming the behaviours by an experienced robot programmer and by using the advanced TiViPE programming environment (Barakova *et al.*, 2013; Lourens *et al.*, 2005; Lourens & Barakova, 2007; Barakova *et al.*, 2014) that improved the robot performance with respect to behavior reliability, bio-inspired object perception, and the proper synchronisation of speech and movements. The known problem of overheating the motors of NAO robot that caused falling over of the robot was resolved by adapting the behaviour of the robot in a way that removing the stiffness from the motors was possible. This way, the robot was invisibly resting during the interaction.

An example of another procedural mistake was that the children were really shocked when the robot said they did something wrong. In this case, the therapist pushed the wrong keyboard key, and this caused the wrong feedback to the children. Potential similar mistakes were prevented by providing a window on the controlling computer that subtitles the speech and behaviour of the robot to follow the scenario progression. A choice of a key is given on this window when the robot has to choose amongst several actions. Such a choice may occur if a child gives an unforeseen in the scenario answer. In this case, a therapist had to press the right key which will redirect the scenario script. Such a window was available also during the pilot test, but at the redesign improvements that increase the clearness were introduced.

As an additional measure, the assistant with high technical skills was present during the experiment, and he made sure that no single error took place during the actual user test.

5.2. Redesigning the robot interaction behaviour

The speaking rate of the robot, and wrong pronunciations was criticised by the children, whilst the children made no remarks on wrong non-verbal behaviours. In the relatively long sessions (about 30 min per session, the option of using pre-recorded voice as in Huskens *et al.* 2013, is very time consuming and costly, so changes in the dialogue cannot be made easily. The changes in the dialogue were the major subject for revision during the overall scenario design. That was the reason to use TTS conversion in the much longer scenarios of the current experiment. During the pilot test, Flamish language was used. During the preparation of the actual test, the Dutch TTS became available, which sounds more natural for Dutch children. In addition, the quality of the robot speech was improved by introducing more pauses for more natural appearance of the speech.

Most design iterations were needed to optimise the robot verbal expressions. The redesign took several iterations during the pilot test. The therapists introduced slight changes in the verbal prompts for the learning moments according to their internalised knowledge. As a future work, we see the need to make possible the therapist program the textual interaction on their own. During the redesign of the overall robot behaviour after the pilot test, the dialogue also needed to be changed. Even after this redesign, two additional iterations needed to be made.

5.3. Redesigning the dialogue management

The opinions on the use of the robot non-verbal behaviour by therapists and HRI specialists were different. The analysis of the human–robot interaction expert showed that the robot was more watched when it is standing or moving, and this increased the engagement of the children and the interest in the training. The therapists and parents of the children, however, recommended reducing the movements when the robot is speaking. Because there was not enough time to find the optimal robot behaviour for the actual test, the non-instrumental gestures that were accompanying the speech of the robot were removed. In place, gaze-based interaction was included to increase the personal attention of the child. This change caused the children to find the robot engaging, as reported in the Social validity questionnaire filled out by the children. We need to further investigate to which degree the reduction of the instrumental movements and the change of the gaze behaviour which is supposed to add a personal character of the interaction have been noticed by the children with ASD. Children with ASD are known to have better perception of details than typically developing persons.

5.4. Steps in the content creation process

The steps that were taken during the design of the experiment, the execution of the pilot test, its critical evaluation, the redesign and carrying out of the actual test and the involved domain specialists in each step is shown in Figure 3.

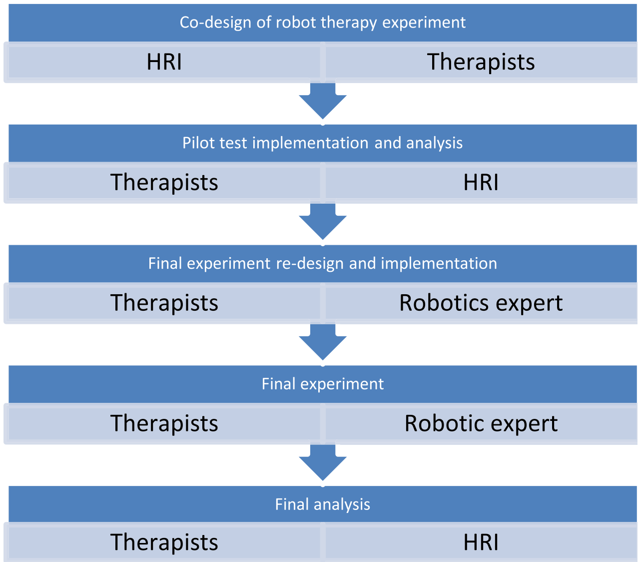

Figure 3: *Major steps on the co-creation process and the involved domain specialists.*

6. Discussion

This paper shows the process of content creation for long-term interaction training with a robot. The interaction continues through several sessions with shared content, where each session has to be engaging enough to continue for 30 min. We designed a LEGO game that takes place between two children and is mediated by a humanoid robot. The existing successful experiments in the use of robots for training children with ASD that are recognised by clinical research have as a leading domain the clinical practice, and the robotics and human–robot interaction specialists have a supporting role. We followed and well understood such design process in previous studies (Barakova *et al.*, 2009; Brok & Barakova, 2010; Huskens *et al.*, 2013). In the current study, by using the co-creation and co-evaluation design methods from HRI and design practices, and positioning the HRI and clinical research on equal grounds, we have contributed to the process of designing well evidenced experiments in the following way:

1. We extended the Pivotal response training (PRT) training scenarios to include longer (30 min) training sessions instead of the few minutes ABA based scenarios with elements of PRT-based scenarios that only lasted a few minutes (as proposed in Huskens *et al.*, 2013). In addition, the constructions from each session were a part of a global construction, that is, the sessions were continuing and anticipated.

2. We designed training sessions that provided sufficient entertainment for the children and gave them the feeling of playing rather than being in therapy. Engaging children in playful interactions with robots has been carried out by many before (Kozima *et al.*, 2005; Robins *et al.*, 2008; Kose-Bagci *et al.*, 2009; Brok & Barakova, 2010; Pop *et al.*, 2013), but these studies did not include a well evidenced therapy framework. Other ABA-based scenarios (to the best of our knowledge) have not been reported yet

in literature, although such experiments have at least been performed by Diehl and colleagues (Diehl *et al.,* 2013). This short publication (Diehl *et al.,* 2013) does not give us enough information to make comparisons or conclusions.

We included the robot as a mediator in the experiment's design and specifically targeted improvement of collaborative play and lack of self-initiation by children with autism. We found that when a robot was used as a mediator, the children found personal attention from the robot the most engaging. In the feedback provided by therapists after the completion of all experiments, it became clear that they prefer dyadic interaction settings between robot and child. The main reason for this is first, to more exactly follow the PRT prompting; and second, the inability of present day robots to respond to more complex situations that occur between two children.

Robins and colleagues (Robins *et al.,* 2005) have argued that a robot should be used as a mediator in training social skills for autistic children. This way, the risk of isolating the children even further from their social environment could be avoided. In game design, interactive embodied agents have shown to promote social and collaborative skills (Barakova *et al.,* 2009; Brok & Barakova, 2010) by mediating the play between two children. We adopted these ideas in the described experiment. However, the humanoid robot is one level of abstraction closer to a human actor than other technology allows and could eventually add to the training of social skills by itself. The appearance of the robot makes the children with ASD to perceive it to as a social agent, and as a result they want the robot to give them personal attention by looking at them, talking to them and being oriented in the direction of the child. This was observed despite of the fact that the children were aware that the robot was at times controlled by a therapist through the notebook that was present in the room.

As a social agent, the robot shows authority during the moments when he is dividing the roles between the children. The children do not complain about their roles when the robot assigned them even when, their behaviour shows that they are not happy with their role. Similar observations are made by Simut *et al.* (2012). In their experiments with a Probo robot, the participant needed a decreased level of prompting to perform the desired behaviour when the story was told by the robot compared with the intervention with the human. There is an alternative explanation for this fact, the perceived inability of the robot to react directly to the children. During the experiment, the children asked questions to the robot, which it was not able to answer. This could be the reason the children to accept their roles without a discussion. The fact that the robot is not able to react to the children disliking their role is also a point for improvement.

There was no consensus between the clinical experts and human–robot interaction experts over the proper ratio of verbal and non-verbal behaviours of the robot. The knowledge providers as therapists and caregivers recommended that the children needed to be given a single stimulus at a time. If the robot is speaking whilst moving its hands, the children are likely to find the hand movements more engaging, which results in them missing the spoken message. The observations from the HRI experts showed that the children are paying more attention to the robot when it moves, and the children are aware of what it was saying at those moments, because they responded to the words with adequate behaviour. The children also glance at the robot is more often when it is standing. In addition, when the children were making their LEGO constructions, and the robot was speaking to them, they did not look at it after the first session. In spite of this, the children clearly showed that they heard and understood the robot's messages, because they acted upon them. These observations can be used in future designs too achieve training goals as defined by the therapists: to increase the amount of time, the children play together and improve the interaction between the two children.

Due to the fact that the therapist was sitting at the table, the children involved her in their play a couple of times. Therefore, the therapist is somewhat influencing the sessions. The behaviour of the robot can also be enhanced on many levels. For example, more advanced behaviour can be implemented by making use of the face and voice recognition, walking movements, grasping movements and the ability to show feelings through his facial expression. In our previous experimental work (Barakova & Lourens, 2013; Huskens *et al.,* 2013), the robot had more advanced motor behaviour with some use of sensory information. The children found this highly engaging, whilst in this experiment, more engagement was earned by the LEGO game itself.

7. Conclusion

This paper shows the added value of the HRI and design approach to improving the clinical utility of robots. The LEGO therapy has been translated to robot training, where the humanoid robot replaces one of the children in the game scenario that follows the design of LEGO therapy. By using the LEGO game-based therapy, long training scenarios can be held without exhausting the possibilities of the robot's actions or having the children lose interest during the training. In addition, the sessions are connected by the continuous design of the game, which spreads through multiple sessions, with the aim of completing an overall LEGO construction. This way, the children anticipate the upcoming session. Game elements that are used in other training practices for children with ASD, such as 'the missing element' were added to increase the entertainment and the learning opportunities provided by the robot.

Prior research on training children with ASD trough LEGO therapy showed increases in the initiations of social contact with peers with ASD or in the duration of social interactions (LeGoff, 2004; LeGoff & Sherman, 2006; Owens *et al.,* 2008).

Our pilot experiment showed more limited improvements—there were increases in social behaviours, but these were not sustained after the training with the robot concluded. We believe that the main reason for that is the short duration and the low intensity of the intervention compared with the studies of LeGoff (2004); LeGoff and Sherman (2006), and Owens *et al.* (2008). For example, in the study of LeGoff (2004), LEGO therapy group sessions lasted 90 min, individual sessions of 60 min were provided every week for 12 to 24 weeks. In the conducted pilot test, weekly intervention sessions that lasted for 30 min, were conducted for 4 weeks, and no individual sessions were provided. Given the limited number and length of sessions in the current study, the children had limited opportunities to practice the different roles and skills.

Increasing of the number and length of the sessions with the robot aims to bring to lasting results of the therapy. To achieve that, in addition to increasing the robot's intelligence and interaction fluency, one needs a sufficient and qualitative content for robot therapy. For the creation of such content, we advocate the need for therapists to be able to create the robot training within a frameworks of continuous game design and to streamline social computing techniques for this purpose.

A major challenge when training children with ASD is keeping the children focused on the therapy. This becomes more challenging when the length of therapy sessions increases. Creating four sessions of 30 min with different but related content and keeping the children engaged is still a great effort. The robot interaction behaviours used in this experiment were not optimal—the robot made a number of mistakes during the sessions, had a limited behavioural repertoire, including a limited number of prompt options, and limited reinforcement options. However, in a Social validity questionnaire, the children rated the robot as exciting, and all the children said that they wished they could have more sessions with the robot. This questionnaire was provided after the final test when the majority of the weaknesses in the robot–child interaction that were detected during the pilot test and, as reported in this paper, were already improved.

The design process of the LEGO intervention indicated that an increase in the personal attention the robot paid to a single child, and creation of dyadic robot–child interactions within triadic games with robots, had positive effect on the children's engagement as well as on the usefulness of the therapy and the building of controllable learning moments. Personalised gaze interactions were used in our final experiment for this purpose, but the correlations between this particular change in robot behaviour and the engagement the children will have has to be investigated in a different study.

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