Developing Child-Robot Interaction Scenarios with a Humanoid Robot to Assist Children with Autism in Developing Visual Perspective Taking Skills

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***Abstract*— Children with autism often find it difficult to understand that other people might have perspectives, viewpoints, beliefs and knowledge that are different from their own. One fundamental aspect of this difficulty is Visual Perspective Taking (VPT). Visual perspective taking is the ability to see the world from another person's perspective, taking into account what they see and how they see it, drawing upon both spatial and social information. In this paper, we outline the child-robot interaction scenarios that we have developed as part of the European BabyRobot project to assist children with autism explore elements that are important in developing VPT skills. Further to this we describe the standard pre and post assessments that we will perform with the children in order to measure their progress. The games were implemented with the Kaspar robot. To our knowledge this is the first attempt to improve the VPT skills of children with autism through playing and interacting with a humanoid robot.**

I. Introduction

Autistic Spectrum Condition (ASC) is a developmental condition that appears in many different forms and varies in its degrees of severity ranging from severe low functioning autism, to high functioning and Asperger's syndrome. One of the most common manifestations of ASC is an impaired ability for social communication and interaction [1]. Many robots have previously been used to encourage social interaction and collaborative play amongst children with ASC [2]. However, to date robots have not been used to assist developing the Visual Perspective Taking (VPT) skills of children with ASC. In this paper, we outline an approach where we use the Kaspar robot to teach children about VPT and develop their skills in this area via a series of progressively more difficult tasks that are implemented as child-robot interaction games/scenarios[1]. Further to this we provide a detailed outline of the pre and post testing procedures that will be used to measure some aspects of the children's development. These testing procedures are based on standardised and well established methods that can be found in psychology literature. This article focusses on the motivation and description of the games, whilst also providing a brief overview of the initial testing that has taken place to ensure that the scenarios flow well and have the capacity to work with children with ASC.

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[1] For the purpose of this article we use the terms 'games' and 'scenarios' interchangeably.

Figure 1. Typically developing child interacting Kaspar robot.

II. The Theory of Mind and Visual perspective taking

Individuals affected by ASC often have great difficulty with Theory of Mind (TOM) and understanding the views and desires of other people [3-9]. TOM is the ability to understand that other individuals have their own thoughts, plans and perspectives, this also extends to the attitudes, beliefs and emotions of others [3]. Because children with ASC struggle to understand that other people do not have the same thoughts as themselves it can cause them difficulty communicating and relating to other people socially. An aspect thought to be associated to TOM is VPT.

VPT is the ability to view the world from another individual's perspective, considering what they see and how they see it [10]. To successfully perform VPT, an individual must consider both spatial and social information. The spatial information required for VPT comprises of the current location of the viewer and the target in the environment in relation to one's self and other person [11-13], whilst the social information utilized for VPT concerns the simultaneous representation of two differing perspectives, judging if and how another individual can see an object [14]. Flavell [10] defines two distinct levels of VPT, the first level (VPT1), is understanding that other individuals have a different line of sight to ourselves. The second level (VPT2) is understanding that two or more people viewing the same object from different points in space might see different things. There is some dispute amongst the scientific community as to a potential relationship between TOM and VPT because both rely on simultaneous representation of two differing perspectives [14]. Some believe that TOM and VPT share common cognitive processes [15], whilst others suggest that they may be entirely separated [16], however the results of studies into VPT amongst children with ASC are somewhat inconsistent [15, 17-19]. Pearson et al. [20] reviewed 13 different studies that focus on VPT and concluded that many children with ASC appear to be able to perform VPT1, but often struggle with VPT2.

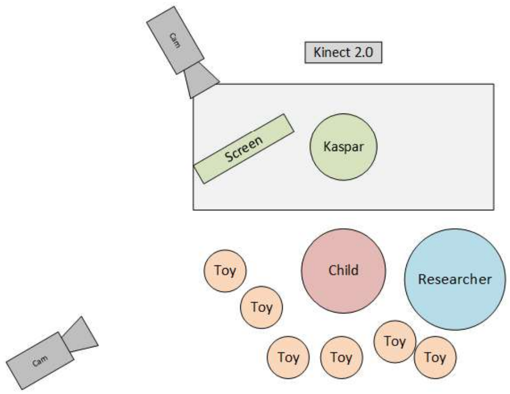

Figure 2. Generic equipment layout.

We propose a new approach to help children with ASC develop there VPT skills using the Kaspar robot [21]. Whist researchers have previously attempted to develop the VPT skills of children with autism using a variety of different strategies [22-24], a robot has not previously been used to assist children in this field. Using a robot to teach children about VPT has a distinct advantage in the fact that the robots field of view can be shown directly to the children using the cameras in the robots eyes and a screen to present the robots perspective. To our knowledge no one has tried to help children learn about VPT using this approach to date.

III. THE CONCEPT

In attempting to devise an approach to teach children with ASC about VPT, we designed 11 games that start out very simple and incrementally become more difficult, but are all focused on the concepts of VPT. The development of these games was based on a number of factors. The primary factor that we initially considered was the literature on VPT and how this related to our previous experience of developing scenarios for children with autism using a humanoid robot [25-27]. Further to this we also consulted teachers that specialised in working with children in special needs schools to gain feedback on the games we devised. To implement these games we used the humanoid robot Kaspar and a screen next to the robot to display what the robot can see from its eyes. The games are centred on the children showing the robot animal themed toys in an appropriate manner in order for the robot to make the sound of the animal and perform gestures which act as a reward for the child. Showing the toys to the robot in an appropriate manner means ensuring that the toy is in the robot's field of view and as such is not too close or too far from the robot's face. The robot will provide feedback to the child if the toy is not being shown in an appropriate manner. Figure 2 illustrates the basic setup of the child-robot interaction scenarios, however there are variations on this setup depending on the game which is being played. There are a number of cameras and a Kinect sensor in the diagram which are used to gather data from the children interacting with the robot during the sessions.

Another aspect considered for these games was the potential applicability of technology to automate some aspects of the games. The games proposed in this paper all have the potential to apply a level of automation to them. The EU Horizon 2020 BabyRobot project, which this research is part of, aims to develop semi-autonomous robotic systems that can work in real world settings and assist with real world problems. Because of this we have to strike a balance between what will be useful for teaching the children and what is possible with the current technology and sensors available.

Note, prior to developing the scenarios, the concept of using the Kaspar robot with a screen showing "what the robot sees", for the children to learn about VPT, was tested with three children with ASC in a special needs school. After this basic proof of concept the tasks were developed and implemented as interactive games and an initial pilot study with one typically developing child was conducted in the laboratory to highlight any potential issues (*see Figure 1)*. Furthermore, field trials with typically developing children were conducted in a primary school as a usability test for the developed games, before introducing these scenarios in the field trials with children with ASC.

IV. THE GAMES

In this section, we outline the games developed and explain their specific objectives.

A. Rules of progression

In order to progress to the next game the child must first complete the game three times consecutively to demonstrate that they have an understanding of what is being taught to them. By taking this approach we can establish how well the child is progressing.

B. Game 1: Show me an animal and I'll make the sound

The first game involves the child showing Kaspar various animal themed toys, from the 6 that are available to the child. In this game Kaspar does not move its head or eyes and looks straight ahead. The child therefore needs to locate and move the toys into Kaspar's field of view. The screen placed next to Kaspar displays what can be seen from Kaspar's eyes. This game allows the child to explore what happens if they move a toy into the Kaspar's field of view, because the toy becomes visible on the screen that shows what the robot can see from its eyes. Once Kaspar can see the toy, the robot makes the sound of the animal being shown to it by the child, which serves as a reward for the child. This game is classed as a VPT1 exercise as the children learn that Kaspar has a different line of sight from their own line of sight. Figure 1 shows how the child is playing game 1 with the robot.

C. Game 2: I'll ask for the animal, you find me the animal

Building on game 1, rather than free exploration, the child now needs to find the animals that Kaspar asks for. The robot will ask the child to show it particular animals, and the child needs to find the corresponding animal and show it to the robot in an appropriate manner in order for Kaspar to make the animal sounds and gestures. This again classed as a VPT1 exercise as the children learn about Kaspar having a different line of sight from their line of sight. However the child needs to collaborate with Kaspar in order to obtain the reward.

Figure 3. Child is moving robot's head to make it look at the toy.

D. Game 3: Make me look and I'll tell you what it is

Similar to game 1, the children have the freedom to show Kaspar any toy without limitation and Kaspar will reward the child regardless of the toy. However, in this game the child directs where Kaspar looks rather than moving the objects into Kaspar's field of view. The objects in the room are placed so that they are viewable by the robot from where it is sitting. In the initial setup the children physically move the robots head to make it look at the toys (see Figure 3). After this, the child uses a joystick to control where the robot looks. Similarly to the first two games this is classed as a VPT1 exercise, reinforcing what had been learnt in the first two games but in a different (interaction) context, it therefore requires the child to transfer what they have learnt in games 1 and 2 to a different game. An important new feature of this game is that the children learn about how someone's physical head movement and orientation affects what they can see.

E. Game 4: I'll tell you what I want to see and you need to show me

Combining aspects from both games 2 and 3, in game 4 the child controls where Kaspar looks, but must direct Kaspar's head towards the animal that Kaspar states that it wants to see. Again this is classed as a VPT1 exercise, reinforcing what has been learnt from the earlier games. However, in this game the children need to direct the robot's gaze according to the robot's intentions, collaborating with Kaspar and understanding the robots intention by directing the robots eye gaze towards the correct toy.

F. Game 5: Collaborative control to meet a common goal

Similar to games 3 and 4, the children must direct where the robot is looking in order for the robot to earn the reward. As in games 2 and 4, Kaspar states the name of the animal that it wants the children to direct its eye gaze towards. However, in this game two children must work together to direct Kaspar's eye gaze. Only if the children work together to meet the shared goal can they achieve the reward from Kaspar. Because it is impractical to have two children physically moving the head of the robot, each child is given a joystick and can each control one access of the heads orientation (up/down, left/right). Again this is classed as a VPT1 exercise, reinforcing what had been learnt from the earlier games, but is also encouraging the children to work together helping to build there collaborative capabilities.

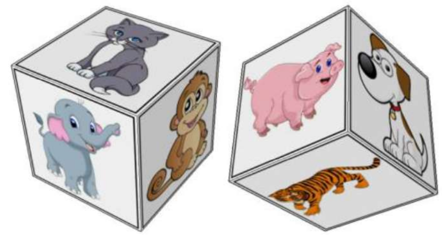

Figure 4. Cube with animal pictures on faces.

G. Game 6: What you see is not the same as what I see

As with game 2 Kaspar looks in one direction only and requests to see particular animals. However, in this task the child is given a cube with pictures of animals on the faces of the cube (see Figure 4). When the child shows Kaspar the requested animal picture on the face of the cube, Kaspar makes the sound of that animal as a reward similar to the previous games. It is important to note that the face of the cube that is towards the child is different from the face of the cube that is facing the robot. This game is classed as a VPT2 exercise because the robot and the child are looking at the same object but see different things. The child needs to understand that what he/she sees is not the same as what Kaspar sees.

H. Game 7: You need to agree for me to play

Similar to game five, two children need to work together and collaborate in order to achieve the reward from Kaspar. Again Kaspar looks in one direction only and two children in this case, both need to show Kaspar animal toys. The children each have an identical set of animal toys that they can show Kaspar. This game differs from game five in the respect that the two children need to collaborate and decide together on the animal they want to show to Kaspar, rather than Kaspar simply telling the children what to do. The children have to show Kaspar the same animal toy at the same time in order for the robot to make the sound of the animal as a reward. This game is focused on developing the children's collaborative and social skills.

I. Game 8: I spy with my little eye…

This game is based on the well-known game I spy, however in this version of the game the child needs to work out what toy Kaspar is looking at from what the robot says and where its head and eyes are pointing. The toys are placed around the room (with sufficient spacing) and the child needs to work out and indicate which toy Kaspar is looking at. The children can indicate this by pointing at the animal or picking up the animal toy and showing it to Kaspar. Unlike all the previous tasks, in this task the child will not have the assistance of the screen because we are beginning to try and encourage the children to work out what Kaspar can see without referring to the screen. This is a very important step because in real life interactions with other people the child cannot see what other people can see via a screen. In these games the screen is simply used as a stepping stone to help teach the children about VPT and at this stage we want to try and get the children to complete the game without the assistance of a screen.

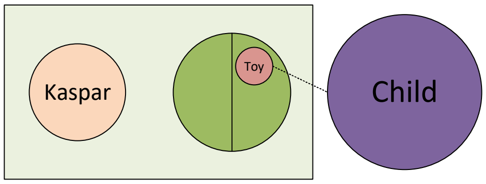

Figure 5. Equipment layout diagram for game 9.

J. *Game 9: What can we see?*

This game is a VPT2 exercise which is inspired by the well-established Sally-Anne test [3] that is a psychological test, used in developmental psychology to measure a person's social cognitive ability to attribute false beliefs to others. Often children with autism struggle to view a situation from another person's perspective and realise that what they want, feel, know and think is different from another person's thoughts and feelings. In this game a physical separator device is placed on the table between Kaspar and the child. As shown in Figure 5, the separator allows three positions: in the first position, the toy can be seen by both, Kaspar and the child. In the second position the toy can be seen by Kaspar only, in the third position the toy can be seen by the child only. In this game the child places one toy in the holder and the researcher moves the holder into one of three positions before Kaspar asks the child questions about the visibility of the object. As with game 8, the screen is not available to the child as a point of reference.

K. *Game 10: Who can see what?*

Similar to game 9, the children answer questions on the visibility of toys placed in a holder, however in this game the children place three toys into the holder and the holder has 3 different positions in terms of the toys visibility to the robot and the child (see Figure 6). Again Kaspar asks the child questions about the visibility of the toys in the holder.

L. *Game 11: Where will I look?*

This game is an alternative implementation of the well-established Sally-Anne test explained in game 9. In this game there are two boxes, a blue box and a red box, both have lids. The child has one toy and Kaspar asks the child to put it one of the boxes then place the lid on it whist Kaspar watches. Kaspar then engages in a standard play activity with the child. After several minutes have passed the robot says it is tired and going to have a quick nap, Kaspar will then close its eyes. Whilst Kaspar's eyes are closed the researcher encourages the child to move the toy into the opposite container and place the lid on it. The researcher then encourages the child to wake Kaspar up to continue playing. When the robot wakes up, the researcher asks the child to point where the robot would look for the toy. The child should point to the last place where Kaspar saw the object if they have developed TOM. Kaspar then states where it thinks the toy is i.e. where it last saw the toy. If the child does not identify this correctly the researcher explains to the child that the robot did not see the child move the toy and would have looked in the container that it last saw the toy in. This is to assist the child in learning about TOM and assess their progress.

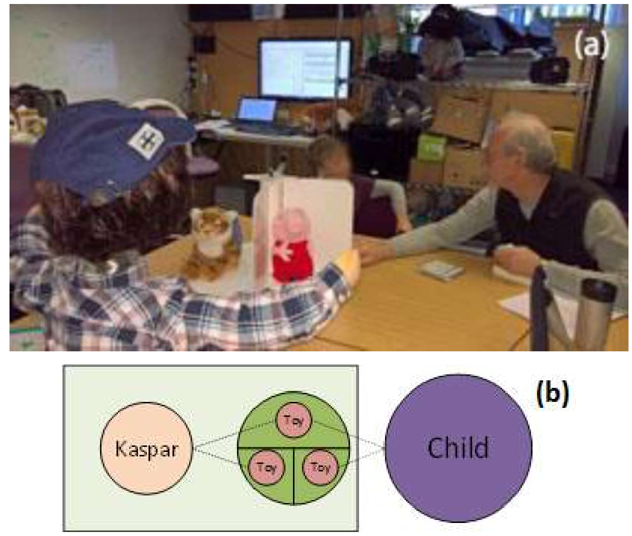

Figure 6. (a) Example interaction, (b) Equipment layout.

V. PRE AND POST ASSESSMENT OF THE CHILDREN

To measure the potential impact of the games on the children, some pre and post assessments are conducted. The pre assessment of the children involves three tests that have previously been used for children with ASC.

A. *The Smarties test*

The smarties test is designed to establish if the child has a theory of mind by asking a series of questions about the contents of a smarties tube [28]. The tube is shown to the child and is asked "what do you think is inside". Very often the child will say either "chocolate", "sweets", or "smarties". When the tube is opened the child sees that there are pencils inside. The pencils are put back in the tube, the tube is closed and the child is then asked what their teacher would think is inside. If the child has a theory of mind they will say smarties or chocolate, if they do not then the child will say pencils.

B. *The Sally-Anne test*

The Sally-Anne test is designed to establish if the child has a theory of mind [3]. However, the advantage of this test is that it is more accessible to non-verbal children because the children can just point to answer questions rather than speak. Two dolls that look different are placed on the table, one is called Sally the other is called Anne. The child has to confirm that they know which doll is called Sally at the beginning of the test. Sally has an empty basket, whilst Anne has an empty box. Sally places a ball into her basket whist she goes out to play. Anne moves the ball from the basket into her box whilst Sally is out. The child then needs to say where the ball is and then where Sally left it. The child is finally asked where Sally will look for her ball when she is back. If the child says the basket then they have a theory of mind, if they say the box this is an indication that they do not.

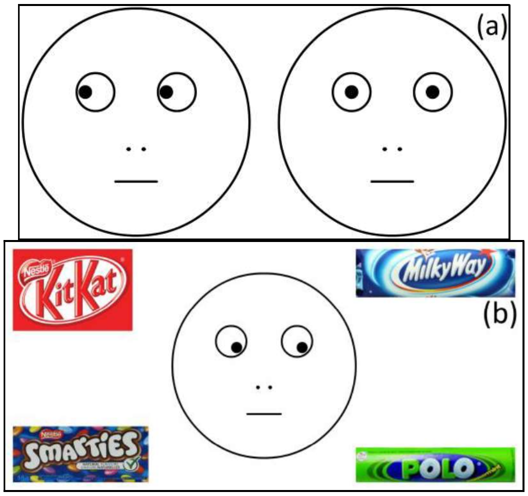

Figure 7. Example questions from Charlie test.

C. *The Charlie test*

The Charlie test is designed to examine the child's understanding of eye gaze [29], which is important for VPT. The child answers a number of questions which revolve around the concept of eye gaze. Figure 7.a shows an example question where the child is asked "which face is looking at you?", whilst the image is directly in front of the child. As the test becomes more complex the child is then presented with pictures of 4 different sweets and asked which one is their favourite (see Figure 7.b). Once the child has selected a

favourite then a face called Charlie is placed in the middle of the sweets looking at something different to what the child stated and arrow is also placed on the sheet pointing at another selection that is not what the child stated or what Charlie is looking at. The child is then asked "What is Charlie looking at?". If the child states the sweet that the face is looking at then this is coded as correct, if the child stated the sweet they chose themselves, this is coded as an egocentric response. If the child states one of the other sweets this is coded as random. The Charlie test consists of 15 questions in total and similar to the Sally-Anne test can be performed with a child that is unable to speak.

VI. A USABILITY TEST WITH A TYPICALLY DEVELOPING CHILD

Before trialling this approach with children with ASC, a usability trial was conducted in the lab to establish how the games would work and to highlight any potential problems with the games before entering a more challenging environment. To test the games a 7-year old typically developing child, accompanied by his mother, visited our lab and volunteered to play the games with the robot. Figure 1 shows the child bringing a toy into Kaspar's field of view, whilst Figure 3 shows the child physically moving the robot's head towards a toy and confirming it is in the robots field of view on the screen. Figure 6 shows a more advanced game where some toys were placed behind partitions so the robot and the child each see different toys, but without the assistance of a screen. The child very much enjoyed the games, but found them very easy which was expected because neurotypical children of this age have developed these skills by this point.

VII. CONCLUSIONS

The initial proof of concept with three children with ASC and the subsequent trial run of the set of developed games with typically developing children, both in the lab and in a mainstream school, were positive and indicated that the games flowed well and the children were able to complete the games with ease. However, using highly structured games with children with ASC, and keeping their attention, motivation and engagement for those sessions poses a difficult challenge. We addressed this challenge by deciding to run the sessions flexibly, i.e. integrate the core VPT games with previously developed games for Kaspar that can help to keep the children's engagement and attention (e.g. tickling the robot, singing a song etc.). We also learnt that some of the phrases and explanations that the robot gave to the typically developing children were difficult for the children to understand. As these games are targeted towards working with low to medium functioning children with ASC, the instructions that are provided to the children would need to be even more focused and phrased in a much simpler language.

VIII. FUTURE WORK

We are currently in the final stages of completing a study with 16 children in a mainstream school and 12 children in a school for children with special needs. The studies in both schools suggest that the children do respond to the robot and engage in the activities developed. Once we have results from the data analysis of the studies we are currently running, we will then adjust the games as necessary and will move towards performing similar studies in an autonomous/semi-autonomous mode by implementing the necessary technological developments to facilitate the interactions and autonomously control particular aspects of the robot's functions [30]. We will use the data collected in these studies to examine what would be required for such a system to work robustly. Our goal is not to replace teachers or therapists but to provide a robotic system as an enjoyable and interactive tool to teach children with autism about VPT.

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