Noname manuscript No.
(will be inserted by the editor)

How Wild is Wild? A Taxonomy to Characterize the 'Wildness' of Child-Robot Interaction

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Received: date / Accepted: date

Abstract When thinking about Child-Robot Interaction (CRI) in the 'wild' or natural settings, many ideas come to mind, such as a home or a school that involve chaotic settings with autonomous robotic devices and people that are freely interacting with them. However, there certainly are degrees of 'wild', and different experimental settings can have varying levels of control in place. It would be helpful to have a common framework to interpret and identify the many different influencing factors or levels of control surrounding CRI experimentation. Having a framework to help towards standardizing evaluation of CRI studies would benefit researchers wishing to identify or plan the varying dimensions present in CRI experimentation. This paper presents a simple taxonomy to characterize the 'wildness' factors in CRI over two main dimensions (Participant and Robotic) that can effect the overall outcome of such studies. The use of this taxonomy is illustrated by its application to current CRI research. Specifically, we use it in reflection to rate six of our CRI trials that have been conducted over a ten year period. From the classification of these studies, a general view of our work so far is outlined and new research perspectives are identified. The application of the taxonomy is also validated by reviewing a selection of other CRI studies.

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Keywords Child-Robot Interaction · Reflection and Planning · Taxonomy

1 Introduction

The domain of Human-Robot Interaction (HRI) investigates all areas of robots and humans interacting together. This subject area is an extremely complex domain and researchers are still investigating the fundamentals of how humans and robots will interact together, which includes how to evaluate the effectiveness of the interaction. Ways in which to analyze 'Human to Robot' or 'Robot to Robot' have been suggested previously. Some involve categorizing multi-robot systems and investigating the difference between heterogeneous or homogeneous robot teams [1]. Some give a more general overview of HRI, listing many different categories such as 'Task Type and Criticality' [35] [34]. Yanco et al., [35] suggest that defining the task, e.g., 'search and rescue' or 'delivery' robot, for HRI is critical. However, in many social robotic systems it can be difficult or impossible to specifically set a task per se. Evaluating the interaction is complicated by the fact that there is a whole plethora of ways in which the interaction can be considered, from task-orientated to social, and evaluated quantitatively or qualitatively. Therefore, it can prove difficult to find standardized dimensions to analyze different HRI experiments. A framework to systematically study how different types of HRI effect the human is required [6].

Robots have great potential to be devices that can be of benefit to children in a variety of ways. As such, there are now many robotic devices available, both within the domain of 'play' or entertainment [22], and also within the research world of child development [3] [12]

[7] [30] [18]. Currently, within the domain of Child-Robot Interaction (CRI), researchers use different methods for investigating interaction with varying levels of 'wildness'. Some researchers test in laboratories [24], some simulate real life environments in controlled areas, such as making playroom's in laboratories [10]. Others use more natural environments, such as playroom's in day-care centers with other toys scattered about [9], or a 'set-up' play room at a private home [20]. We ourselves have used a variety of different settings, from a cold hard laboratory to making the setting as comfortable as possible in the child's natural environment, to test differing and similar research questions.

While there is great potential for CRI, there are many different factors that must be improved upon before natural interaction is achieved. Experimenting in real-world environments can provide both many benefits and also its share of difficulties. Certain experimental settings may create difficulties such as the environment may be too challenging for the capabilities of a robotic device. Certain conditions may need controlling, such as the amount of light available or the number and type of obstacles in the room, to compensate for the limitations of the robot and for the context of the intended study. Changing or engineering the environment may be necessary to address specific research questions and experimental methodologies. However, this may have varying effects on users or participants. For instance, controlled conditions help to conduct rigorous, quantitative, statistically significant analysis, but may also create an effect on the outcome. This is especially true when it involves mobile robots: the mobility of the robot can cause randomness which makes it difficult to rigidly control the surrounding conditions, sometimes making natural and qualitative evaluations preferable. All the difficulties involved in real-world experimentation may explain why it is difficult to replicate experimental HRI scenarios [4] [17], or to situate CRI work and outcomes.

Because children are more likely to interact with robots in a social manner in natural settings rather than a task-orientated manner, robots should have the ability to gain the interest of the children in noisy, uncontrolled, dynamic environments. Without the child's interest, there is no hope for the robot being able to serve, for instance, as a development or teaching tool. The robot must also be able to sustain this interest over a period of time so as to continue in its required role. Therefore, from an engineering perspective, designing a robot that can interact efficiently with children requires trials that go beyond what can be reproduced in laboratory settings. There are certainly varying levels of 'wildness' or controlled conditions which can be appropriate at different stages of CRI, which can be influenced by the experimental settings, the participants and the behavior exhibited by the robot. It would seem that using a combination of controlled and 'wild' settings to incrementally build a path to success [29] is appropriate. Consequently, characterizing the 'wildness' factor of these iterations can help analyze and guide this progression.

So we began to wonder: How wild is wild? and How does this influence CRI outcomes in terms of level of interest? More specifically, over the past decade, we have conducted many different types of CRI trials, ranging from formal to relaxed, from single session to multiple sessions, in a laboratory to home environments. Looking back over these studies, we have observed similar initial levels of interest in our robots. However, we have found varying levels of sustained interest even when it is the same robot exhibiting the same behavior. We have also observed that the conditions surrounding the study may have an impact on how much and how long a child wants to interact with a robot.

To explain this varying sustained interest level, we make the hypothesis that the overall dimensions of the interaction (the conditions surrounding the study) may play a factor in the outcomes. We believe that it is important to have the ability to be able to systematically document or interpret CRI studies in terms of the influence the experimentation conditions may have on CRI outcome. To help both in reflection of and in planning CRI, this article suggests a taxonomy that allows researchers (either designing or evaluating CRI trials) to characterize the degrees of 'wildness', or oppositely the degrees of control, involved in CRI experimentations. It investigates how 'wild' or controlled the environment really is, both viewed from the participant's perspective and the robot's perspective. Unlike other taxonomies which suggest that classifying the task will automatically classify the robot's environment [35], we have chosen to classify the environment separate from the task. This is because a robotic device can be performing the same task or actions but in very different environments and with different people, e.g., a social robot in a noisy home environment or a social robot in a controlled hospital environment, and this can have different outcomes.

This article is organized as follows. Section 2 describes the taxonomy and the scale we propose in which to interpret CRI experimentations. Section 3 illustrates how to use the taxonomy by describing and evaluating six different studies conducted with our spherical robot named Roball. Section 4 presents our thoughts derived from using the taxonomy to identify new ideas for future studies. It also characterizes CRI experimentations conducted by others and reflects upon work within this field.

2 A Taxonomy of 'Wildness' in CRI

This taxonomy considers the level of control placed both on the participant and on the robot. Two main dimensions, **Participant (P)** and **Robotic (R)**, are identified and are each subdivided into three areas:

- **Autonomy (A)** - Details the amount of freedom placed on either the participant or the robotic device during the trial (e.g., are participants free to move about as they choose during the trial, are cameras pointed at the participant; is the robot confined to a pen or does it wander and get stuck under television cabinets).
- **Group (G)** - Details the amount within the group (human) and the amount and type of group (robotic). We have set the numbers of participant and robot based on our empirical experience. Within the robotic group we consider robots, toys and other non-human autonomous agents (e.g., pets), as all of these can be interplay agents in a CRI experimentation.
- **Environment (E)** - Covers details of the environment from the human's point of view and from the robot's point of view. A relaxing environment for a human can be noisy and difficult to negotiate for a robot.

Table 1 presents the taxonomy's rating table. A scale is given of one (no level of control) to nine (high level of control) for each of the categories. Notes on each of the six categories covered are given to clarify their meaning. As it may be difficult for a user to set clear borders between categories, we identify each one by a number, i.e., one, three, five, seven and nine, and add an in-between number (two, four, six and eight) to specify when an element is somewhere between the descriptions given. Also, if a single trial contained elements of more than one category, it is possible to indicate different ratings in a single category. Listed here are the descriptions of the categories we are proposing to characterize the level of control in CRI experimentations.

- **PARTICIPANT AUTONOMY (PA)**
  - **Free** - No restrictions on interaction with the robot. The participants feel completely comfortable to interact in anyway they choose. No time restrictions. No focus on participants. The participants do not feel part of an experiment. The participants feel no inhibition.
  - **Natural** - Minimal restrictions on participants interaction with the robot, e.g., *"Interact in anyway you want but do not break the robot"*. No time restrictions. Minimal focus on the participants. No person present in the role of the experimenter.
  - **Comfortable** - The participants are given certain information about how to interact with the robot(s), e.g., *"This robot will serve you drinks"*. Some time restrictions apply. A certain amount of focus is on participants. Cameras are kept to a minimum. No person present in the role of the experimenter.
  - **Directed** - The participants are given limited instructions, e.g., *"You must be close for the robot to see you, Press the red button if the robot does not understand you"*. Some time restrictions apply. There is focus on the participants that they are aware of. Cameras are used. There is a person present that is clearly in the role of the experimenter.
  - **Controlled** - The participants are given instructions on how they can interact with the robot. Time restrictions are given and adhered to. Cameras are used. Focus is fully on the participants and they are aware of this. There is a person present that is clearly in the role of the experimenter.
- **PARTICIPANT GROUP (PG)**
  - **Large Group** - There are more than eight participants.
  - **Medium Group** - There are six to eight participants.
  - **Small Group** - There are three to five participants.
  - **Paired** - There are two participants.
  - **Singular** - There is only one participant.
- **PARTICIPANT ENVIRONMENT (PE)**
  - **Free** - This environment is likely to be the participants own home or a place where the participant enjoys being, e.g., an area where a party is being held at school. It is an area where the participant do not feel inhibited at all. The participants feel as though they can behave however they choose in this environment, e.g., running around, jumping on furniture.
  - **Natural** - This is a known environment to the participants. It could be their school or play group. The participants feel comfortable, relaxed and at ease in this environment. However, they realize there are certain normal restrictions on their behavior, e.g., no jumping on the furniture.
  - **Familiar** - This could be any natural noisy environment such as schools, play groups, etc. This is not necessarily the participants usual environment but would be an environment that partici-

Table 1 Levels of control in relation to Participant and Robot influences.

	Level of Control								
	NONE		**LOW**		**MEDIUM**		**MODERATE**		**HIGH**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
PA	Free		Natural		Comfortable		Directed		Controlled
PG	Large		Medium		Small		Paired		Singular
PE	Free		Natural		Familiar		Adapted		Sterile
RA	Autonomous		Fixed		Combination		Wizard of Oz		Remote-Controlled
RG	Plethora		Multi-Agent		Robot+Anim.		Robot+Inanim.		Singular
RE	Open		Secured		Challenging		Engineered		Controlled

pants would be comfortable in. The participants may display a more controlled behavior in this environment.

- **Adapted** - This is probably not the participants normal environment. This is an environment that is typically a comfortable environment, e.g., a school that has been altered to make the experiment possible, e.g., floors having lines to enable robot navigation.
- **Sterile** - This environment is likely to be at a laboratory or any other environment that is strictly controlled. This is either not the participants normal environment or an environment where their actions are tightly controlled.

– **ROBOTIC AUTONOMY (RA)**

- **Autonomous** - The robotic device is completely autonomous. The robot receives no input from human beings as way of controlling any aspect of decision-making. The robot uses its own sensors to navigate, interact and make decisions.
- **Fixed** - The robotic device follows fixed spatio-temporal command patterns, regardless of the situations occurring in the environment.
- **Combination** - The robotic device can be controlled by a human for some of the time and also have some autonomous behaviors or fixed spatio-temporal command patterns.
- **Wizard of Oz** - The robotic device is controlled by a human being not present in the environment that the robot is functioning. However, it is possible for the human being to see the robot, e.g., through a one-way mirror. The robot does not make any decisions by itself.
- **Remote-Controlled** - The robotic device is controlled by a human being that is present in the same environment. The robot does not make any decisions by itself.

– **ROBOTIC GROUP (RG)**

- **Plethora** - There is any combination of robotic devices, autonomous agents (e.g., pets), animate toys and inanimate toys.
- **Multi-Agent** - There is multiple robotic devices or autonomous agents (e.g., pets).
- **Robot+Animated** - There one robotic device plus other animated toys.
- **Robot+Inanimated** - There is one robotic device and other inanimate toys.
- **Singular** - There is only one robot.

– **ROBOTIC ENVIRONMENT (RE)**

- **Open** - No confinement of the robot. This is a completely natural environment. It can have obstacles that can prove hazardous to the robot, such as stairs. No consideration is given with regard to making the environment safer for the robotic device.
- **Secured** - No confinement of the robot in a natural environment, e.g., lots of obstacles, varying lighting conditions, noisy, different floor coverings and levels, and finally, the possibility for objects to move such as people, toys, animals. This is a natural environment that is used by humans such as an office or a home. This environment is probably very difficult for the robot to navigate on a general basis. However, considerations are given to make sure the robot does not come to harm.
- **Adapted** - A natural environment but adapted to be suitable for the robot, e.g., some objects removed to make space. Challenges like varying floor covering and lighting may exist.
- **Engineered** - The area is prepared and designed so that it fits with the robot's capabilities. Sensors may be placed to help the robot navigate. Flooring coverings are such that they enable the robot to easily maneuver. Lighting is controlled. The environment is likely to be simulated or manufactured, e.g., a room at a laboratory. However, there will have been efforts to make this seem friendly and welcoming like adding natural human environment, e.g., a home, so there will be obstacles such as furniture.
- **Controlled** - This environment is likely to be stark and utilized because it is easy to adapt

Fig. 1 Roball, a spherical robot.

Fig. 2 Study 1: A 10 month old toddler plays with Roball in a natural home environment.

for the needs of the planned experimentation, e.g., confined spaces, controlled conditions, etc. Likely locations are a laboratory or a school hall.

3 Illustrating the Use of the Taxonomy

To validate our taxonomy and illustrate how it can be beneficial, we examine some of our experiments that have already been conducted with Roball, our spherical robot [15], [16] shown in Figure 1. Roball has the ability to wander around the environment and avoid obstacles. It can also adjust its speed of motion (speed up and slow down) and play sounds such as vocal messages or music. Roball can either function autonomously, be remote controlled or can be used in a combination of the two states. Roball has evolved over the ten years that we have been using it, with upgrades and addition of sensors and interactive devices (e.g., lights). This has all occurred during a natural development cycle of attempting new ways and methods to create interaction with children.

Roball has been used in a broad variety of studies, not conducted within a series, with many different factors to each of these studies ranging from duration and setting, to the age of the participants, to the behavior exhibited by the robot. Factors that are universal for each of the sessions are that Roball's function was always to act as a mobile, moving toy, and Roball always displayed some form of autonomous decision-making capabilities for navigating the environment. In the following, we list six studies conducted in chronological order involving Roball, and examine how the 'wildness' factors effected the interest of the children.

STUDY 1 – As shown in Figure 2, Study 1 involved a longitudinal study with very young child (aged from 10 months to 30 months) playing with Roball (PG = 9) in a very relaxed atmosphere [14] [15]. The objective of this study was to simply see how a young child responded to interacting with Roball and how Roball could sustain physical interaction in such unconstrained conditions. The experiment was in fact being conducted by the child's parents in their own home (PA = 2). Therefore, the environment from the child's point of view was very natural (PE = 2). There was very limited camera use and this was the family camera, and therefore the child was used to seeing it being used. The environment was left as it was typically and the robot had to negotiate obstacles such as chairs, a sofa, different floor coverings, etc (RE = 2). Roball wandered about autonomously and used mercury tilt sensors to react to a child's interaction by adjusting its motion and by generating vocal messages and sounds (RA = 1). Roball was the only robot present in the trials (RG = 9). The outcome of this trial was very favorable. The robot managed to keep the child interested for a long period of time. The child played with the robot for approximately 30 minutes and was upset when the session ended. Also, when the robot was reintroduced over the 20 month period (in similar settings), the child was happy to play with the robot again each time. Overall, it seems that this was an enjoyable experience for the child.

STUDY 2 – This series of trials were held at an elementary school (see Figure 3 (left)) [25] [29]. The purpose of this study was to gather data from Roball's onboard accelerometers to examine how the data can be analyzed to identify interaction patterns. In this study, three typically developing boys between 5 and 7 years of age participated. Each of these children played with Roball by themselves (PG = 9) and on two different occasions. Some children were known to the experimenter in a social context. The experimental area was known to the children; it was in fact a classroom that was used at certain times by the children. However, the area was not left natural: a pen was constructed (2.5 m × 2 m) from wooden planks for the sessions (PE = 7, RE = 7). There were no other toys or robots in the environment (RG = 9). The children were asked to step inside the pen and play with Roball. Roball was started and was programmed to only wander autonomously in the environment, with no interaction capabilities (RA = 2). The experimenter maintained a professional manner with the children and attempted not to speak to them outside of giving the instruction to play with the robot (PA = 7). The trials were initially conducted for five minutes, but this seemed too long for the children to hold their attention span, and so the length of each trial was shortened to four minutes. It therefore revealed difficulties in sustaining a child's interest in such a setting.

STUDY 3 – This study was conducted at the same time as Study 2, and had the same objective and protocol except that it was held at a play group which met in a church [25] [29]. The sessions were conducted in the basement, this was so that the child participating was not disturbed by the play group. Although the building was known to the children, the area (the basement) where the sessions were conducted was not known to the children. This area was very stark and not welcoming (PE = 9). Five typically developing boys between 5 and 7 years of age participated in this study. Each of these children played with Roball by themselves on two separate occasions (PG = 9). Some were known to the experimenter in a social context. A pen was constructed from wooden planks (2 m × 2 m) at the location to hold the sessions in. There was always at least one other adult present watching the sessions, and any adult that was present was asked not to talk whilst the sessions were being conducted. Trials were held over a two week period. The trials were initially conducted for five minutes but this seemed to long for the children to hold their attention span, and again the length of the trials were shortened to four minutes. Therefore, similar outcomes to Study 2 in terms of child's interest were found.

STUDY 4 – This study was held in a loft area of a home, as shown in Figure 4 [27] [29]. The objective of this study was to see if it was possible to detect and adapt to interaction coming from children using patterns of activities derived from on-board analysis of accelerometer data. Four typically developing boys aged between four and seven participated. A pen (2.5 m × 2 m) was constructed as an experimental area using four small wooden walls. Every experiment was videotaped for post data verification. The children were taken to the loft area one at a time for interaction with Roball (PG = 9). The experimenter remained impartial to the children and simply told them that they could play with Roball (PA = 7). The pen was used to avoid the robot coming into contact with non-interactive instances (e.g., obstacles RG = 9). Despite being held in a home, the experimental area was still quite stark and controlled (PE = 7, RE = 9). Roball wandered around inside the experimental area autonomously (RA = 1). In this study, Roball had audio and simple adaptation built into its behavior, such as giggling if spun. Adapting Roball's behavior to a child's interaction revealed to generate interest.

STUDY 5 – This study was held at a daycare center in Québec, Canada (see Figure 5). The objective of this study was to compare how the children responded to three autonomous behaviors (RA = 1) exhibited by the robot [26]. The participants in this part of the trial were five typically developing children (four boys and one girl), aged 2 to 4. By analyzing its onboard accelerometer data, Roball was autonomously able to respond in different ways to the children's interaction, e.g., by speeding up, flashing lights, stop and play an audio clip that said "Play with me" if it did not sense any interaction from a child. The approach to this study was to make each session as natural as possible (PE = 3) and, in this vain, to limit the use of cameras, etc. This was an attempt to limit the 'audience effect'. The experimenter spent a lot of time just helping out in the daycare where the study was to be held. This was to familiarize with the children in an attempt to not be seen as an experimenter. There was an area set aside for the trial which was normally used by the children. The area had large pieces of furniture that were moved to the side, but there was still an array of different places for the robot to stuck under, e.g., antique cot, television cabinet. Within the area there were three different floor coverings: hard wood, carpet (rug) and brick work in front of the fire place (RE = 4). Also, at times there was one or two other toys within the area, such as balloons or a toy truck (RG = 7). Having these other toys in the area did not seem to take the interest away from the robot. Trials were conducted in two conditions:

(A) One child was allowed to interact with Roball. Due to the relaxed nature of the trial at times, some other children did come into the experimental area (PG = 8). However, they were told that they could not touch the robot until it was their turn. We conducted this part of the trial over a six day period. The exact dates were dictated by attendance of the same children and convenience for the daycare. Each child played with the robot in three separate sessions of 5 minutes (PA = 3). This study showed that it is possible to adapt a robot's behavior to a child's interaction in a relaxed environment when the area being used is sufficiently uncluttered, and also that conditions surrounding this study pro-

Fig. 3 Study 2 (left) : A child plays with Roball at the school. Study 3 (right): A child interacts with Roball in the basement of a church. The pen in which the experiments took part can be seen in both pictures.

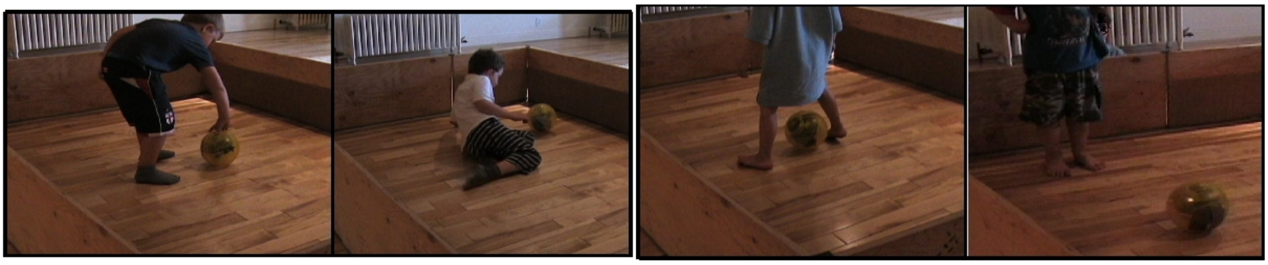

Fig. 4 Study 4: Four boys interact with Roball. It is possible to see the pen that was used to create an experimental area.

Fig. 5 Study 5 (A) (left): The oldest child of the group interacts with the robot. It is possible to see the balloons that were in the experimental area for some of the sessions. In the background, some of the objects the robot had to negotiate are visible, i.e., a television cabinet and a sofa. STUDY 5 (B) (right) : Roball is in an environment with six children.

duced a long sustained interest compared to other studies. It was the experimenter's opinion that four of the five children seemed happy to play with the robot on multiple occasions, and the interest level did not really seem to fall. There are many possible reasons for this, including the fact that the robot was programmed with three different behaviors. However, we believe that a large factor may have been the natural way the experiment was conducted. Only one child did not seem overly happy to play with the robot, and he seemed conscious of the experimenter and the other children watching. We believe that this is what was interfering with his enjoyment.

(B) One off-session with the group of children interacting with Roball. The group of children (PG = 3) was allowed to have unconstrained (within limits) free interaction with Roball (see Figure 5 (right), PA = 2). Some children played with the robot the whole session, and some played with the robot intermittently. It was the experimenter's opinion that the children really seemed to enjoy this session. Even the child who did not seem very confident in his interaction in trials (A) seemed to greatly enjoy interacting with Roball in a group. The children chased after Roball and laughed. Generally, it was an extremely lively, excited and joyful session. Playing with Roball in a group revealed to be a very enjoyable experience.

STUDY 6 – This study was conducted in a natural home environment (PA = 2, PE = 2, RE = 2), as shown in Figure 6. The objective of this study was to investigate over a long period of time how a child responded to a robotic device (RA = 1) compared to other similar devices and toys. Roball displayed the same behavior as listed in Study 5. It was conducted over a period of ten months. The same child (aged 12 months at the beginning and 22 months at the last trial) participated in each of the sessions. There were many different 'toys' at each session from 'toy robots' to 'stuffed toys' (RG = 1). The child was involved in 17 sessions with Roball for an overall duration of approximately 2 $\frac{1}{2}$ hours. Most of the time the child played with Roball by himself, but on occasions there was either his brother present or his brother and a friend present (PG = 8). The child's interaction styles ranged from hugging the robot to throwing the robot, rolling on the robot, hitting the robot, moving like the robot, running around the room, appearing to be proud of the robot and showing it to a friend. It appears that the child's reaction to the robot ranged from being overjoyed by the robot and actively interacting with it, to not paying the robot any attention but still being aware of its presence or to being annoyed with the robot one time when it stopped playing music. This study truly showed natural CRI and that this child interacted with the robot in a manner that is very natural due to being exposed to the robot for a long period of time.

Fig. 6 STUDY 6: A child plays with Roball in a cluttered home environment. It is possible to see other toys, furniture, weight machines and different floor levels.

4 Discussion

Table 2 summarizes how we rated our studies using our taxonomy. We ordered our studies based on the observed level of interest manifested by the children. It is possible to see that we conducted experiments with different level of controls, mostly in terms of PA, PE and RE, and that we observed the most interest from children in conditions with the least control on the environment (PE & RE) and their behavior (PA). The taxonomy rating of our past studies will provide a basis for comparison of the results of new trials, and will help us keep in mind the evaluation metrics required to make such comparisons possible. More specifically, we are currently conducting trials that have low levels of control on the environment (PE & RE) but have high control on the robotic device (e.g., remote-controlled RA), as shown in Figure 7. This approach is being applied to a study that is investigating the effectiveness of Roball as a therapeutic device and an assistive tool at a child's rehabilitation center. The children play with Roball as a form of rehabilitation and they are instructed in actions such as 'chase the robot'. Early feedback from the care workers is that the remote control behavior is very important to them so that they can use Roball as an effective tool. In future work, we also plan to conduct trials:

- in wilder conditions, i.e., with multiple Roballs, multiple children, in 'wildness' conditions not yet explored (e.g. PA = 1, PE = 1, PG = 1 to 5, RG = 1).
- that would allow us to pinpoint how much the influence on the child's interest comes from the participant autonomy, the participant environment or the participant grouping.

Although rating all other CRI work is out of the scope of this article, we have used the taxonomy to classify a brief selection of other works. Table 3 summarizes our rating of the selected related work based on what we understand from their publications. This list is not meant to be exhaustive but to illustrate how the taxonomy could be used. For instance, it is possible to see from Table 3 that there is a whole range of ways in which researchers are conducting CRI studies, from controlled to wild. There are various reasons to use either controlled or wild conditions to surround a CRI study and each plays its own role. It was not possible to extract common variables for evaluating how

Table 2 Classification of CRI studies using Roball.

	PA	PG	PE	RA	RG	RE	Level of interest
Study 2	7	9	7	2	9	7	Low sustained interest
Study 3	7	9	9	2	9	9	Low sustained interest
Study 4	7	9	7	1	9	9	Interest
Study 5 (B)	2	3	3	1	7	4	High interest
Study 1	2	9	2	1	9	2	High sustained interest
Study 5 (A)	3	8	3	1	7	4	High sustained interest
Study 6	2	8	2	1	3	2	High sustained interest

Fig. 7 A child plays with Roball in a cluttered rehabilitation setting. It is possible to see other toys, equipment and a therapist directing the child in interaction with the robot.

the level of control of these experiments affected their outcome. However, use of the taxonomy provides an indication of the levels of control placed over CRI experimentations by other researchers. From our observations of these works, most of the 'wildness' appears to come from the participant autonomy, participant environment and robot autonomy.

5 Conclusion

Child-Robot Interaction (CRI), although progressing, is still in its infancy, and researchers have a long journey ahead of them until the ultimate goal of robots that can adapt themselves to interact with children in a variety of different manners and in a variety of different environments (including noisy 'wild' environments) is reached. There are many different factors involved in CRI experiments, such as duration and settings (e.g., level of control), age of participants, cognitive or physical ability of participants, level of instruction given, behavior exhibited by the robot and of course the experimental objectives. Many more experiments need to be conducted to explore the entire space of possibilities that can affect CRI outcomes. This makes it difficult to interpret results or to evaluate what has been done and what remains to be explored.

Instead of exploring the space of CRI experimental factors, this taxonomy examines the experimental constraints put on the participants and the robots, expressed in terms of 'wildness' or level of control. We suggest the use of the proposed taxonomy as a tool that can help researchers to better interpret, situate, plan and ultimately understand the outcomes of CRI experimentation based on the levels of control that surrounded the experimentation. Interaction is a highly complex and dynamic phenomenon, with all the experimental conditions being interdependent. Many HRI researchers would agree that real-world experimentation takes a great amount of effort [19], but many also agree it is a necessary and worthwhile endeavor [6] [2] [11] [23]. Experimenting in real-world environments with children is certainly challenging, and we believe that we can learn a lot from all trials.

Using this taxonomy to grade or classify dimensions of studies makes it possible to reflect on factors that may or may not play a role in the interaction process. However, we do not claim that this taxonomy is complete or sufficient to provide an overall answer to experimental outcomes. For instance, the PG does not consider the relationship a child may have with other members of the group, and the RG category only considers motion as the distinguishing criterion, which is certainly incomplete considering the difference regarding the children's perception of robots and animals [13]. CRI is a young research area, and as additional CRI studies are conducted, the taxonomy will certainly evolve to make finer distinctions and cover additional factors. Our hope is that this taxonomy can serve as a starting point to better understand factors surrounding child-robot interaction, and eventually to explore the possibility of broadening the taxonomy to characterize human-robot interaction in general.

Acknowledgements F. Michaud holds the Canada Research Chair (CRC) in Mobile Robotics and Autonomous Intelligent Systems. This work is funded by the Fonds Québécois de la Recherche sur la Nature et les Technologies.

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Table 3 A summary of various studies that have investigated CRI

	PA	PG	PE	RA	RG	RE	Comments
Tanaka [32]	2	1	2	1	1	2	Nat. envir., longitudinal, mobile auton. robot
Kozima [8]	2	1	2	7	1	5	Nat. envir., longitudinal, fixed controlled robot
Kanda [7]	4	1	3	1	9	4	Nat envir, 18 day trial, mobile auton. robot
Michaud [16]	4	9	3	1	9	3	Mobile auton. robot, play group setting
Werry [33]	3	7	7	1	9	9	Paired children, stark school room, auton. robot
Robins [21]	5	7	4	5	9	9	Fixed controlled robot, longitudinal, school room
Melson [13]	8	9	9	1	3	9	Controlled conditions, mobile auton robot
Salter [28]	8	9	9	1	9	9	Laboratory conditions, mobile auton robot,
Duquette [5]	8	9	8	9	7	9	Rigidly controlled for stats analysis

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