Designing Socially Assistive Robots for Paediatric Rehabilitation

(In Situ Design for Ongoing Clinical Deployment)

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Abstract

Physical rehabilitation relies critically on patients adhering to a prescribed rehabilitation programme. This is made especially challenging in paediatric rehabilitation, where children often lack an understanding and motivation to comply with typically uncomfortable and repetitive exercises. This poses significant challenges for physiotherapists and families, tasked with ensuring exercise programmes are completed, and performed correctly. For hospitals and rehabilitation clinics, valuable resources can be tied up delivering such care, while for parents and families, rehabilitation can be a stressful and emotionally draining experience. Socially Assistive Robots (SARs) are an emerging technology for paediatric health care applications, offering versatility, portability and configurability that can target the needs of diverse patient cohorts. While previous research has established the potential benefits of SARs in paediatric rehabilitation, there remains a significant gulf between proof-of-concept and the on-going deployment of SARs in rehabilitation therapy. Critical to this objective is the key question addressed in this thesis: How SARs can be designed and evaluated to deliver rehabilitation therapy for on-going clinical deployment in busy hospital settings.

To this end, this thesis presents a three-phase in situ design and evaluation process for SARs in health care, emphasising frequent stakeholder engagement and on-site development. The design process is employed to develop and test software for a general-purpose humanoid social robot (NAO) to serve as a therapeutic aid for rehabilitation therapy in Melbourne's Royal Children's Hospital. Unlike previous research, this thesis puts focus on key design decisions and the integration of the robot into existing clinical practice for on-going clinical deployment. The design process consists of an Exploratory Phase (Phase 1) to elicit a set of basic roles and requirements; an Iterative Development Phase (Phase 2) to test and evaluate in situ the stakeholders' perceptions of the prototype; and an Integration Testing Phase (Phase 3) to explore the needs and requirements for the integration of the SAR into daily on-ward use, where parents operate the robot to deliver rehabilitation without physiotherapists or technical supervision.

Through the application of this novel design process, this thesis contributes novel insights into the perceptions and attitudes towards SAR's in paediatric rehabilitation. Results are presented from survey and observational data, spanning three key user groups: therapists, patients and parents. In so doing, the prototype has delivered more than 60 rehabilitation sessions to 24 different patients. This evaluation is performed concurrently with its iterative development towards a system capable of being operated without a therapist, or engineering support.

This thesis further contributes an evaluation of the SAR's integration into on-ward care. Case studies of four week-long trials with patients and their families using the developed SAR are presented, focussing specifically on the system's integration into on-ward clinical care. To support this study, this thesis further contributes new observable metrics to evaluate the quality of care delivery when using the SAR without a therapist present. These are derived from interviews with physiotherapists after using the SAR in their care delivery.

Through the combined results presented, this thesis provides the most comprehensive exploration and evaluation of SAR's for paediatric rehabilitation to date. This thesis concludes that the presented three-phase design and evaluation process has been central to this, providing key new insights into what SARs must be in order to meet key needs for rehabilitation, and be readily integrated into highly dynamic on-ward settings. Such considerations are paramount for their acceptance, and necessary for any clinical evaluation of such technologies.

Keywords: Socially assistive robots; Rehabilitation; Children; Field studies; Health care; Physiotherapy

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Declaration

This thesis contains no material that has been accepted for the award to the candidate of any other degree or diploma. To the best of my knowledge, this thesis contains no material previously published or written by another person except where due reference is made in the text of the examinable outcome.

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Felip Martí Carrillo
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Chapter 1

Introduction

1.1 Research Motivation

For many people with impaired mobility, functional outcomes can be improved through appropriate medical treatment rehabilitation. The main objective is to empower people with mobility impairment to enhance their independence and quality of life [47]. Rehabilitation programmes are an important aspect of medical interventions aimed at improving physical function.

Successful physical rehabilitation relies critically on patients repeatedly performing strengthening exercises [166]. While adults generally understand this basic requirement, adhering to a prescribed programme of often uncomfortable, repetitive exercises can be challenging. For paediatric patients this is made especially challenging, with many young patients not able to comprehend the reason for performing what are often monotonous and sometimes painful rehabilitation exercises. Thus, more targeted efforts are needed to motivate and guide paediatric patients through rehabilitation programmes.

Intensive rehabilitation programmes typically prescribe several sessions per day. For example, young patients with Cerebral Palsy (CP) typically undergo up to two weeks of intensive rehabilitation as in-patients after musculoskeletal corrective surgery, in which up to three sessions of rehabilitation are performed each day. For patients and families, this can be a stressful, and anxiety provoking time. For hospitals and rehabilitation clinics, promoting compliance and adherence also ties up valuable resources. While paediatric physiotherapists are well equipped with a range of skills and resources to optimise session outcomes, time constraints and other hospital demands mean that not all prescribed rehabilitation sessions can be attended by a therapist. Thus, children often go through their rehabilitation session with the help of their parents, allied health professionals, or if old enough even by themselves at least once per day. Parents' lack of comprehension of the rehabilitation programme or lack of time, as well as children's lack of compliance with the prescribed exercises are defining challenges for paediatric rehabilitation.

Aids and strategies to enhance paediatric rehabilitation outcomes have been well explored. Simple game play with toys to more technological interventions such as video games, and/or virtual reality have been considered and applied in paediatric rehabilitation contexts. While such options have been shown to be effective, game play typically requires the dedicated time of the therapist, and technological options to date, while promising, often lack the versatility, portability and configurability required to meet the needs of diverse patients, as well as the operational needs of a busy hospital setting. While research into such interventions is on-going and promising [89], there remains a need for consideration of alternative therapeutic assistive devices.

1.1.1 Social Robots for Paediatric Rehabilitation

Advances in robotics (in particular sensor technologies and electronics) and artificial intelligence (e.g., facial detection [246], object recognition [141], natural language processing [33], etc.), combined with a growing commercial interest has seen the emergence of social robots for health care applications [183]. Socially Assistive Robots (SARs), robots designed to assist human activity and recovery through social interaction [53], have shown promising results in a range of health care settings, including aged-care [238], Autism Spectrum Disorder [195] play therapy [11], and physical rehabilitation [240].

Indeed, most recent research exploring SARs in the paediatric rehabilitation context use the general-purpose NAO robot [40]. For rehabilitation, this robot offers a versatility of use-cases not present in other alternative technology options, and thus it has been the primary robot of choice in recent research exploring how it might assist in rehabilitation therapy [132, 235], and provide motivational statements while doing the exercises [67]. Other research has been done in the incorporation of external sensors to improve the robot's interaction with the patient [78, 176]. The NAO robot's wide use in SAR research, relatively low cost and global availability makes it an attractive choice for rehabilitation applications.

While previous research has established the potential benefits of SARs for rehabilitation (and paediatric health care generally), the vast majority of this work has been focussed on proof-of-concept. Little attention has been given to how SARs may be effective. There has not been study examining how such robots may be designed and evaluated appropriately to deliver on-going therapeutic support and integration into a busy hospital setting. This is a critical aspect of the SAR's design, and one that remains largely unaddressed. This is the primary focus of the research presented in this thesis.

1.1.2 Designing a SAR for On-going Clinical Deployment

The work presented in this thesis aims to develop a robot to socially assist paediatric rehabilitation patients at Melbourne's Royal Children's Hospital, with focus on the integration of the SAR into existing clinical practice for ongoing clinical deployment. Design of a SAR for such an ambitious use-case critically relies on a process of design that adequately engages with, and addresses the needs of key stakeholders. To this end, the first contribution of this thesis is a three-phase in situ design approach for SARs emphasising frequent stakeholder engagement and on-site iterative development. The thesis presents the software development for the NAO robot following the proposed three-phase design process: exploratory (Phase 1), iterative development (Phase 2), and integration testing (Phase 3).

The exploratory phase is required to understand the needs of the clinical setting. It started 8 months before the beginning of the author's PhD candidature, however forms part of the larger design process presented in this thesis, from which the SAR's key roles and design decisions are derived. This thesis does not focus on the process of deriving roles for a SAR (Phase 1), but rather, on the impact of these choices when deployed into clinical care, and implementation decisions that impact its performance in a real-world clinical setting.

Input from all the different stakeholders during the exploratory phase elicited a set of roles and requirements guiding the development of a first SAR prototype. Phase 2 consists on the iterative development and in situ testing of the prototype in weekly patient sessions. The prototype guides patients through their prescribed rehabilitation exercises, employing pre-programmed exercise demonstration, coaching and motivational statements under the supervision of an adult or carer.

While Phase 2 provides new insight into the needs of a SAR in this clinical context, Phase 3 seeks to explore and evaluate the needs and requirements of the SAR's integration into daily on-ward use with dedicated patients over a week of rehabilitation sessions. The identified use-case in this thesis is the daily use of the robot operated by a parent on-ward without physiotherapists or technical supervision. This significantly extends on both Phase 2, and previously explored use-cases for SARs in paediatric rehabilitation.

This thesis will argue that this multi-phased in-situ design process offers significant benefits for the development of SARs, providing deeper understanding of minimal requirements, and the operational context in which it must work. It is further argued that the emphasis on co-design and frequent stakeholder engagement is a key component of success, allowing care-givers the opportunity to feedback into the design process.

1.1.3 Evaluating a SAR in the Context of Clinical Deployment

The weekly iterative development of the prototype (Phase 2) also requires effective methods of evaluation. This thesis emphasises the importance of gathering data from all key stakeholders, using multiple sources of data collection. To this end, as part of the Phase 2 development process, the acceptance of the prototype was evaluated with all key stakeholders, with results spanning observational data, survey data, and post-study interviews. It is argued that these results provide the most thorough examination to date of the perceptions and attitudes of therapists, parents and patients towards a SAR for rehabilitation, offering new insights into their design for health care contexts generally.

The evaluation of the SAR prototype must also consider how the robot performs over time, and how stakeholders' attitudes towards the robot change. Special attention should be given to therapists, who are the primary gate keepers of the technology's adoption into clinical practice. To this end, this thesis presents results captured over sustained periods of operation and repeated use, and also from follow up semi-structured interviews.

The introduction of a general-purpose robot (NAO) into clinical practice necessarily impacts on how care is delivered. While the system offers potential benefits, it imposes new demands on supervising care givers. It is therefore important to understand how these demands impact sessions, and therapists' attitudes towards assisting the SAR when required. Thus, this thesis will further explore the impact of the robot in therapy delivery.

In order to evaluate how well the robot integrates when in daily use, acting as a proxy for therapists (eg., on-ward and outside of scheduled sessions), the evaluation should also consider the quality of care delivery. This requires the identification of appropriate observable qualities upon which to base such assessment. This thesis derives an observational checklist from interviews with physiotherapists to evaluate the SAR's performance on-ward, under parent or guardian supervision only. The evaluation method will be used in the mentioned scenario, presenting a few case studies.

This thesis will argue that the design process and evaluation methodology proposed provides the most thorough examination of SARs for rehabilitation in the context of ongoing clinical deployment. This thesis will critically examine the processes adopted, and from these findings, offer new insights into how SARs can be better designed and equipped to meet the operational and therapeutic needs of their target application.

1.2 Research Questions

In pursuing the goal of developing a SAR for on-going clinical deployment as a therapeutic aid, this thesis addresses a critical primary research question not yet addressed in the literature:

Thesis Research Question. *How can we design and integrate a general purpose social robot into existing paediatric clinical practice for ongoing clinical deployment?*

From this primary research question, a set of important sub-questions are derived, which are outlined below.

In-Situ Design of a Socially Assistive Robot for On-Going Clinical Deployment

In order to integrate new technology into existing clinical practice, the design methodology has to be carefully considered. Generally, technology designed in a lab environment has only limited opportunity to interact with the intended final users. To this end, this thesis proposes and evaluates an in situ multi-phase design process that directly targets the needs of the intended final users of our SAR. Through this process, the following research question is addressed:

Research Question 1. *What roles and operational requirements must a socially assistive robot fulfil to perform effectively as a rehabilitation aid in on-going clinical deployment?*

Focussing on the design process presented in this thesis, these further research questions are addressed:

Research Question 2. *What are the advantages and disadvantages of an in situ design process when designing and evaluating a socially assistive robot for use in health care settings?*

Research Question 3. *How can an in situ design process for socially assistive robots be effectively implemented in a busy health care setting?*

Evaluation of a Socially Assistive Robot for On-Going Clinical Deployment

To successfully integrate the SAR in a hospital environment, a thorough understanding of its impact on care delivery, and the perceptions and attitudes of its role as a therapeutic aid from all primary stakeholders is needed. New technology will not be used if it is not accepted by its final users, particularly in busy operational contexts such as hospitals. Through this thesis's proposed in situ evaluation process, the following key questions are addressed:

Research Question 4. *What factors impact the acceptance and attitudes towards socially assistive robots designed to guide paediatric rehabilitation sessions?*

Through this, the following sub questions are also addressed:

Research Question 4.A. *How do these attitudes change with experience?*

Research Question 4.B. *How do these attitudes differ between therapists, patients, and their parents/guardians?*

Evaluating Socially Assistive Robot Integration in Clinical Practice

In order to study how well a robot integrates when in daily use in an on-ward hospital setting without physiotherapists' supervision, it is important to understand what physiotherapists look for in a successful rehabilitation session so that the robot's performance can be gauged. Therefore, another research question addressed in this thesis is:

Research Question 5. *Upon what metrics can we evaluate the success of a SAR in delivering rehabilitation therapy without physiotherapist supervision?*

Integration of Socially Assistive Robots for On-ward Care

In preparation for full deployment of the system and a planned future clinical trial, case studies are presented in which patients will have daily sessions with the robot over the course of a week. These case studies specifically aim to evaluate the effectiveness of the SAR over multi-day sessions with a single patient, addressing the following questions:

Research Question 6. *What factors impact the integration of a socially assistive robot into daily, on-going use in hospital setting?*

Research Question 7. *What factors impact the quality of rehabilitation care delivered using a socially assistive robot when a physiotherapist is not present?*

1.3 Contributions

The main contributions of this thesis are:

- A novel in situ design methodology for the development of SARs in health care settings.
- New insights into the implication of deign choices for SARs for paediatric rehabilitation, and in on-going clinical use.
- The first long-term evaluation of a SAR for paediatric rehabilitation that accounts for patient, parent and therapist attitudes and perceptions, and in the context of on-going use in a busy hospital setting.
- New insights into the extended and repeated use and integration of SARs in uncontrolled on-ward settings, presenting the first study of this kind for SARs delivering paediatric rehabilitation.
- The most comprehensive examination to date of physiotherapist attitudes towards SAR and the implications of SAR integration in their care delivery.

Some results and analysis presented in this thesis have been published in peer-reviewed conference and journal articles:

- **Martí Carrillo, F., Butchart, J., Knight, S., Scheinberg, A., Wise, L., Sterling, L., McCarthy, C.** (2016) Help me help you: A Human-Assisted Social Robot in Paediatric Rehabilitation. *Proceedings of the 28th Australian Conference on Computer-Human Interaction* (pp. 659-661). New York, NY, USA: ACM. `https://doi.org/10.1145/3010915.3011858` [135].
- **Martí Carrillo, F., Butchart, J., Knight, S., Scheinberg, A., Wise, L., Sterling, L., McCarthy, C.** (2017) In-Situ Design and Development of a Socially Assistive Robot for Paediatric Rehabilitation. *Proceedings of the Companion of the 2017 ACM/IEEE International Conference on Human-Robot Interaction* (pp. 199-200). New York, NY, USA: ACM. `https://doi.org/10.1145/3029798.3038382` [136].
- **Martí Carrillo, F., Butchart, J., Knight, S., Scheinberg, A., Wise, L., Sterling, L., McCarthy, C.** (2018) Adapting a General Purpose Social Robot for Paediatric Rehabilitation through In-situ Design. *ACM Trans. Hum.-Robot Interact.* 7(1), 12:1-12:30. `https://doi.org/10.1145/3203304` [137].

- **Martí Carrillo, F., Butchart, J., Kruse, N., Scheinberg, A., Wise, L., McCarthy, C.** (2018) Physiotherapists' Acceptance of a Socially Assistive Robot in Ongoing Clinical Deployment. *Proceedings of the the 27th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN).* `https://doi.org/10.1109/ROMAN.2018.8525508` [138].

Other publications resulting from the work presented in this thesis for which I have contributed include:

- **Butchart, J.; Harrison, R.; Ritchie, J.; Martí, F.; McCarthy, C.; Knight, S.; Scheinberg, A.** (in press) Child and parent perceptions of acceptability and therapeutic value of a SAR used during paediatric rehabilitation. *Disability and Rehabilitation.* `https://doi.org/10.1080/09638288.2019.1617357` [24].

1.4 Thesis Structure

Chapter 2 - Literature Review

Chapter 2 provides a critical summary and analysis of the relevant literature. The chapter introduces SARs as a viable option for paediatric rehabilitation, offering potential benefits for patient motivation, compliance and emotional well being. It further argues that there is a significant gap in the literature relating to the design and deployment of such systems for on-going clinical use, motivating the core contributions of this thesis.

Chapter 3 - An In Situ Design Process for Socially Assistive Robots

Chapter 3 provides the first contribution of this thesis, a design process for SARs in health care settings. The chapter presents the three-phase design and evaluation of this thesis, and present results from the first phase of this process, conducted prior to the commencement of my PhD candidature. From the findings of this exploratory first phase, the proposed roles, requirements, and design decisions for the adaptation of the general purpose NAO social robot as a rehabilitation aid for ongoing clinical deployment are reported. Part of this chapter has been published in the ACM Transactions on Human-Robot Interaction [137], and presented at the 2018 IEEE/ACM International conference on Human-Robot Interaction in Chicago.

Chapter 4 - In situ Development and Performance Evaluation

The design process of the SAR includes the iterative development and in situ testing of the prototype in the Royal Children's Hospital in Melbourne. This chapter presents the iterative prototype improvements identified and completed during this in situ testing and evaluation phase (Phase 2) of the project. It also provides an overview of the system performance in weekly therapy sessions, as part of the clinical care of paediatric patients undergoing post-surgical rehabilitation.

Chapter 5 - User Acceptance Evaluation

Chapter 5 reports on the participant perceptions and acceptance of the SAR prototype delivering therapy in the Royal Children's Hospital in Melbourne. Results are presented from data collected from patients, parents and therapists over a period of 1 year and 3 months of approximately weekly use of the SAR. Preliminary results from this study, focussing only on physiotherapist data, have been published and presented at the 2018 IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN) [138].

Chapter 6 - Evaluating the Clinical Integration and Impact of a SAR

This chapter presents the results of post-Phase 2 follow-up interviews with four physiotherapists who participated in the Phase 2 evaluation study. The chapter presents metrics derived from these interviews that aim to assess the quality of care delivered with the assistance of the SAR, and its general integration with clinical practice.

The chapter further explores the physiotherapists' perceptions of the SAR impact on their ability to deliver care, and to attend to patient needs. Preliminary results of these data have been published in the Proceedings of the 28th Australian Conference on Computer-Human Interaction [135].

Chapter 7 - Socially Assistive Robot Integration in an On-ward Hospital Setting

In line with Phase 3 of the design process, this chapter reports a set of case studies in which evaluate the integration of the iteratively developed SAR prototype when deployed in daily use. Specifically, the chapter reports observations and survey data from one week of deployment with individual patients in an uncontrolled, on-ward hospital setting. Four case studies (including a pilot) are presented in this chapter in which parents deliver therapy to their child without researchers or physiotherapist supervision.

Chapter 8 - Discussion, Conclusion and Future Work

This chapter presents the overall findings of this thesis, including an evaluation of the design process, encompassing all integration and acceptance data. It concludes with an outline of key questions and guides for the design of future SARs for clinical settings.

Chapter 2

Literature Review

This thesis explores how to integrate a Socially Assistive Robot (SAR) for ongoing clinical deployment in paediatric rehabilitation. Before presenting the novel contributions of this thesis, I provide background and a review of relevant literature. The literature review is presented in four parts. First, I briefly describe what is rehabilitation, the challenges, the role of motivation, and describe the medical conditions of the participants in the studies at the Royal Children's Hospital (Section 2.1). I will argue that robots have shown promising results overcoming some of the challenges in rehabilitation, for example patients' adherence and motivation in their prescribed programme. Thus, the second part of this chapter presents a thorough review of the relevant literature on robots in paediatric healthcare (Section 2.2), with focus on the main application: SARs in physical paediatric rehabilitation. One of the main gaps of SARs in physical paediatric rehabilitation, and a novel contribution of this thesis, is the consideration of a design methodology for the development of the SAR in health care settings. Thus, I review relevant design methodologies previously applied in the SAR context and Human-Robot Interaction (HRI) more generally (Section 2.3). The future deployment of a SAR will have to be evaluated using common methods used in human-robot interaction studies. Thus, the fourth part of this chapter is dedicated to evaluation methods for human-robot interaction, with particular focus on acceptance and perceptions of SARs (Section 2.4). Finally, I summarise this literature review, outlining how the research questions of this thesis address specific gaps in the research (Section 2.5).

2.1 Paediatric Rehabilitation

In this section I briefly describe the most common physical disabilities of the participants in the studies presented, the important role of rehabilitation for people with motor impairments, and the challenges in paediatric rehabilitation. One of the most common challenges in rehabilitation is the patients' adherence in their prescribed programme. Thus, the last part of this section surveys existing therapeutics aids used to increase patients' motivation and engagement in rehabilitation.

2.1.1 Physical Disabilities

The World Health Organization defines disability as an umbrella term for impairments, activity limitations, and involvement in life situation restrictions [165]. Physical disability thus is an impairment affecting physical functioning of a person, mobility, or fine motor skills, altering normal daily life. The Australia Bureau of Statistics reports that in 2012 approximately 3% of Australian adolescents (13-17 year old), 2% of the primary school aged children (5-12 years old), and 1.4% of infants (0-5 years old) had some kind of physical disability [6]. Cerebral Palsy (CP) is the most common physical disability among children in Europe [26]. Other physical disabilities that can affect the gross motor function of children include: Spinal Cord Injury (SCI), Acquired Brain Injuries (ABI) due to accidents or Stroke, and Spina Bifida (SB). Some of those medical conditions can be chronic, however, with the appropriate medical treatment, rehabilitation, and/or assistive devices, individuals can be empowered to live independently [47].

The next section briefly introduces the most common disabilities among patients covered in this thesis below.

Cerebral Palsy

As noted above, CP is the most prevalent cause of mobility impairment among children. There are 3135 people registered in Australia that were born with CP between 1993 and 2006, with an occurrence rate of 2.1 per 1,000 births [2]. Similar ratios have been estimated in different European registers from the 70's to the 90's [26].

Experts in the preclinical and clinical sciences define the term CP as:

> *A group of permanent disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of*

> *cerebral palsy are often accompanied by disturbances of sensation, perception, cognition, communication, and behaviour, by epilepsy, and by secondary musculoskeletal problems* [185].

In other words, CP defines a group of disorders caused by brain damage in areas associated with muscle control during brain development. There is no known cure for CP, and its effects on mobility and motor function are for life. People with CP may also exhibit behavioural, communication, and cognitive deficits, depending on the nature of the brain damage [185].

Though CP has no cure, associated symptoms can often be improved following appropriate treatment and therapy. Single-Event Multilevel Surgery (SEMLS), for example, is considered the standard care for children with CP experiencing fixed musculoskeletal deformities. With SEMLS, the objective is to improve gait and motor-functioning in a single operation, and a single hospital admission [188]. Before SEMLS was introduced as a standard, patients underwent different operations at different times to correct musculoskeletal deformities, suffering multiple hospital admissions and rehabilitation periods during their childhood [7]. After SEMLS post-surgery recovery, a crucial period of rehabilitation begins in which such patients undergo intensive rehabilitation of between 3-5 hours per week [220]. In many cases, particularly for patients with high needs, patients stay at the hospital for a period of 1-2 weeks performing up to 3 sessions of rehabilitation per day. SEMLS and the post-operative rehabilitation protocols have shown that the improvements in gait and function still remain after 5 years from the surgery [221], underscoring the importance of complying with rehabilitation.

Gross Motor Function Classification System

The gross motor function of a patient with CP is classified into five different levels according to the Gross Motor Function Classification System (GMFCS) [167]. Those levels are divided in two age bands: 6-12, and 12-18 years old. The description levels for children (6-12 years old) are the following:

Level I: Children are able to walk, climb stairs without physical assistance, run, and jump. However, they have balance, speed and coordination limitations.

Level II: Children have limitations for running, jumping, and walking long distances. They need assistance such as a handrail to climb stairs.

Level III: Children use hand-held mobility devices to walk indoors, and wheeled mobility for long distances. When climbing stairs they need supervision or assistance. Assistance is required for sit-to-stand and floor-to-stand transfers.

Level IV: Children use powered mobility or physical assistance to ambulate. They use floor mobility such as crawling or rolling at home. Assistance is required for most of the transfers.

Level V: Children are transported in all cases, and need assistance for all the transfers. They may have very limited floor mobility, or are carried by an adult.

Palsy can also be classified topographically, based on the affected area of the body [90]. For example:

Diplegia: affects both sides of the body. In general, palsy affects the mobility of both legs, and to a lesser extent may also affect the arms.

Hemiplegia: palsy that affects only one side of the body. Arm and leg in either left or right side are affected.

Quadriplegia: palsy that affects both arms and legs. It could also affect some trunk and face muscles.

Although hemiplegia, diplegia and quadriplegia are the most common terms, monoplegia and triplegia are terms can also be used to refer palsy in 1 or 3 limbs respectively.

Acquired Brain Injury

Acquired Brain Injury (ABI) is damage to the brain that has occurred after birth [227]. ABI is not related to birth defects or other developmental disabilities such as CP. Some of the many different reasons that can cause ABI are:

- Stroke (blockage to the brain blood vessels suppliers [16]).
- Brain tumours.
- Infections.
- Trauma such as from high impact (also referred to as Traumatic Brain Injury [145]).

Depending on the severity of the ABI and the brain area involved, patients might suffer from different conditions [178], for example: epilepsy, diminished sensory abilities (vision, touch, smell), physical disabilities, impaired ability to think and learn, among others. These may be temporary, or permanent.

Spinal Cord Injury

Spinal Cord Injury (SCI) describes damage to the spinal cord, usually due to trauma caused by car accidents, sporting injury, falls, or other medical conditions. The spinal cord conducts sensory and motor information between the brain and the body. Spinal cord injury thus might result in a loss of motor function and/or sensory ability [208].

The level of damage and effect is classified by the International Standards For Neurological Classification of Spinal Cord Injury (ISNCSCI) [112]. In short, the level of injury can be defined as:

SCI Complete: No transmission of messages between the damaged area and the rest of the body. No sensory and motor function below the damage.

SCI Incomplete: There is partial loss of transmission of messages beyond the injuries. However, some sensory and/or motor function below the damage still exists.

Spinal cord injury can also be classified by the affected area of the body:

Tetraplegia: Injury in the cervical area of the spinal cord affecting the sensory and/or the motor function of the arms, trunk, legs, and pelvic organs.

Paraplegia: Injury below the cervical area of the spinal cord not affecting the arms. However, the sensory and/or the motor function of the trunk, legs, and pelvic organs might be affected.

Spina Bifida

Spina Bifida (SB) is a general term referring to a range of malformations at birth, relating to the spinal cord, and the brain [149]. It results from the malformation of at least one spine vertebra, exposing the spinal cord and the nerves on the surface of the back instead of being inside of the spinal canal.

The effects of spina bifida vary depending on the location and the severity of the malformation. The malformation can be located in the cervical, thoracic, or lumbar spinal region affecting the nerves below the abnormality [209]. Among others conditions, a reduced sensation and a degree of palsy of the lower body are common symptoms of the spina bifida.

Approximately 1 in 1,200 pregnancies are affected by spina bifida in Australia [207], with no known cure. However, people can learn to manage its effects with the help of appropriate medical treatment, physiotherapy, medication, medical aid, etc.

2.1.2 Rehabilitation and Challenges

Non chronic medical conditions can be recovered from with the appropriate medical treatment and rehabilitation, but people suffering from permanent conditions can also improve their quality of life with appropriate medical treatment, rehabilitation, and assistive devices [47].

In this thesis, the focus is on rehabilitation for the improvement or recovery of motor function, particularly, the restoration of the ability to perform a movement [166]. There is evidence that exercise, such as repetitive induced movements, contribute to promote brain plasticity (ability of the brain to change) which has the potential to improve motor function, and protect against neurodegeneration (loss of neurons structure and function) [113].

Walking is a basic functional skill, thus the recovery of gait is a primary goal for many patients in rehabilitation settings to be independent and improve their quality of life [98]. Before ongoing locomotor activities such as walking, patients typically undergo intensive rehabilitation exercises to improve their strength, balance, and transfers such as sit-to-stand and vice versa [69]. In the context of this thesis, physical rehabilitation for young patients with the medical conditions described above is typically delivered by a physiotherapist in 30 minutes sessions. In addition, inpatients are normally prescribed exercises to be done on their own, or under the supervision of a parent or a carer, and outpatients might also be prescribed a rehabilitation programme to be done at home.

Goals and goal-setting in rehabilitation is considered a fundamental part of the rehabilitation programme [201]. Professionals usually frame with the patient's family the goals in terms of physical outcomes related to the patient's mobility and physical independence. However, it is reported that goal-setting also presents challenges in rehabilitation [18]. For example: patients not necessarily wishing to engage or participate in the rehabilitation programme, so the goals are not archived; parents wanting less responsibility when setting goals for their young child; time constraints from therapists and parents; and also the education to parents in order to transfer the basic skills of the goals in rehabilitation could be challenging.

Health professionals have reported the importance of patients' motivations and adherence to their prescribed programme for rehabilitation outcomes [144]. Motivation could be indicated by the patient's engagement during the treatment, and also by the patient's compliance with the rehabilitation. Different factors might affect the motivation of the patient, for instance the rehabilitation environment, the patient's personality, their age, their cultural norms, among others [130].

Existing therapeutic devices that have been used to improve patient engagement in rehabilitation are surveyed in the next subsection.

2.1.3 Existing Therapeutic Aids for Rehabilitation

The repetitive movements required for rehabilitation are neither very motivating nor stimulating per se. Thus, different kind of devices have been used widely to improve motivation in rehabilitation, trying to make it an enjoyable activity and increase patient's compliance. The common idea behind these devices is to bring some fun into the therapy, or to design fun activities to complement rehabilitation. Examples include video games, virtual reality, and social robots.

Video Games

Crank handles integrated into video games in order to control the player character have been used to motivate patients in doing repetitive movements (the cranking action) required for rehabilitation. More recently, commercially available video game consoles controlled by movement have also been used to encourage patients in doing active activities. In this subsection some examples are presented.

GameCycle integrates an arm crank into a video game in which the patient controls the speed of the car with the crank [245]. The objective behind GameCycle is to improve the aerobic activities of adolescents with spinal cord dysfunctions. Eight adolescents suffering spina bifida tested GameCycle 3 times per week during 16 weeks and indicated it was enjoyable. The authors suggested that GameCycle is an appropriate exercise device to improve oxygen uptake and maximum work capability.

Another device integrated into different video games is a stationary recumbent bicycle in which players pedal to move their associated avatars [87]. Their target population is CP children with GMFCS levels I, II and III. Five children tested the device in an 8 week home trial and found the games fun and engaging. Future work in home trials will evaluate the efficacy of the games in improving rehabilitation outcomes and social engagement.

Researchers also have studied how commercially available gaming consoles such as Wii (Nintendo) or Xbox (Microsoft) can be used to enhance rehabilitation or aerobic activities for people with different forms of motor disability. Some examples are presented below.

The Wii console was used to augment the existing rehabilitation programme for an adolescent with CP (GMFCS level III) in 11 training sessions [43]. The goal of the gaming sessions was to improve the patient's visual perception skills, posture control, and motor function. Researchers speculate that the patient's improvement in all three categories was due to the intensity of the treatment the patient underwent, thanks to the gaming system.

Xbox with its Kinect camera (an RGB-Depth sensor) is another console used to promote physical activity while playing. Voon et al. [236] report a study with patients from the Burns Unit at the Royal Perth Hospital, Western Australia. Some patients played Xbox Kinect Sports Pack as part of their upper limb recovery. Patients in the video games group reported more motivation in the rehabilitation, and performed more minutes of exercise activity than those who did not.

Ten children with impaired balance and coordination (ataxia) also used the Xbox Kinect video games during an 8 week study [95]. The ataxia symptoms were significantly reduced after the 8 weeks, and children showed improvements in their gait.

Chang et al. [29] developed rehabilitation software, which uses the Kinect camera, for upper limb rehabilitation. The goal of their system is to motivate independent physical rehabilitation prescribed by the therapists. Two adolescents with CP enhanced their motivation for rehabilitation, and improved exercises performance.

Appropriately chosen video games have been shown to be a useful complement to therapeutic rehabilitation or to enhance physical activities for people with different forms of motor disability. However, therapists have noted that commercially available video games offer limited options to individualise the treatment parameters [122], or to calibrate the difficulty level for specific patients [5]. Patients could get frustrated if the exercise is too difficult for them, this happens if the video game is cognitively too overwhelming [122], or too challenging for their medical condition, for example when using their impaired hand [217].

General purpose social robots, for example, are versatile devices which can be programmed and adapted to the individual needs of each patient. Those robots can be programmed with similar exercises currently being used in clinical practice which are adapted to the patient's needs. For instance, less cognitive demanding exercises, or exercises adapted to the medical condition of the patient.

Another concern reported by therapists is about the quality of the exercise when using video games [5]. It is very common for patients with impaired mobility to use compensatory strategies in order to perform movements that require their limbs with restricted mobility. The use of compensatory strategies when using the games can be harmful for their recovery [217]. Thus, the main goals of the video games, which normally are to achieve the highest score or to complete missions, might not be aligned with the goals of rehabilitation which are to perform the exercises correctly.

Virtual Reality

Virtual Reality (VR) is a simulated environment experienced though a VR headset or surrounded by multi wall projected environments [212]. Users can move and explore the virtual environment using controllers or sensors attached at their body. This virtual environment can be used for different applications, some examples are: medical or space training, recreating heritage or archaeological elements, entertainment, and for healthcare therapies. The main idea behind VR in rehabilitation is to immerse patients in a virtual world while encouraging them to do active activities.

Following the same objective as video games, VR has been extensively used to improve motivation in rehabilitation or to enhance physical activities for patients with different medical conditions. For example, 4 children with CP undertook a 4 week individualised training programme incorporating VR during 2 hours per week [31]. Using a sensor glove and a 3 dimensional environment, patients performed reaching and grasping tasks of static and moving objects. The authors report that some of the children showed improvement in different measures such as fine motor skills, reflexes, locomotion, among others.

Stroke is another medical condition in which VR has been used to improve rehabilitation outcomes. Saposnik et al. [194] did a randomized clinical trial with 2 groups of stroke patients using the VR Nintendo Wii (VRWii) gaming system versus recreational therapy. Patients played sport and cooking games available with the VR Wii console. After 4 weeks of intervention, the authors reported that VR gaming technology is a safe technology that can promote motor recovery. The outcomes of VR versus recreational therapy were also explored in a larger study with 376 patients with impaired arm mobility due to stroke [228]. The two different groups undertook 2 hours of therapy, delivered 5 days per week over 4 weeks. Their results support previous evidence suggesting that VR treatment can be a beneficial therapeutic option for post-stroke patients.

Also considering stroke, Laver et al. [121] reviewed 72 studies where VR was used for stroke rehabilitation. The authors conclude that VR, as a substitution for conventional therapy, is not more beneficial to improve upper limb function, however, it could be beneficial if used as a complement to traditional therapy. After a thorough review of the literature, similar conclusions were reported by Pietrzak et al. [172] who could not find strong evidence that the use of VR improves motor and function for people living with post traumatic brain injuries. However, the authors suggest that VR can be an alternative for people living with geographical constraints. VR has also been applied to the enhancement of balance and mobility for people with Parkinson's disease. For example, Mirelman et al. [148] reviewed 12 different studies, reporting a potential benefit using these technologies. However, due to a lack of randomized controlled trials, they cannot conclusively assess the efficacy of these techniques. Similar conclusions were reported by Snider et al. [206] when reviewing VR studies done with children with CP.

While VR can offer a boost in patients' engagement in rehabilitation, there are also some limitations to consider similar to video games. These include: the use of compensatory strategies from commercially available gaming systems which are not specifically designed for people with motor impairments [123]; or the lack of affordable, accurate, and ease-of-use tracking sensors to track the user's performance [152].

The versatility of a general purpose social robot can also overcome some of the issues presented with VR systems. For example, the use of a social robot in rehabilitation does not mandatorily require to incorporate accurate sensory systems as it will be discussed in this thesis. Patients can also use compensatory strategies when doing rehabilitation exercises with a robot, however, the robot can be programmed and configured with alternative exercises that can mitigate this issue.

VR also requires patients to wear equipment during the session (such as a headset), or alternatively a dedicated a room to recreate the projected environment should be provided. Patients refusing to wear the headset, or space limitations in a busy hospital are some of the challenges to consider when using VR in hospital environments.

Social Assistive Robots

In recent years, social robots have also been considered to enhance rehabilitation outcomes (a through review is given in Section 2.2). As mentioned before, social robots are versatile devices that can overcome some of the issues of video games or virtual reality systems.

Table 2.1 summarises the main advantages and disadvantages of video games-based systems and socially assistive robots.

Table 2.1: Summary of advantages and disadvantages of video games-based systems and socially assistive robots

	Video Games-based Systems	**Socially Assistive Robots**
Advantages	• Can Improve motivation in rehabilitation encouraging patients doing physical activities • Commercially available video games ready to be used (e.g.,[43, 236]) • Can be designed to promote exercise for existing rehabilitation exercises (e.g., [87, 245])	• Can Improve motivation in rehabilitation encouraging patients doing physical activities • Versatile devices • Can be programmed with existing exercises rehabilitation exercises • Can be adapted to the individual needs of the patient
Disadvantages	• Limited options to individualise treatment parameters [122] • Limited options to calibrate the difficulty level for specific patients [5] • Exercises can be too overwhelming or too challenging for some patients [122] • Goals of the video games might not be aligned with the goals of rehabilitation [217] • Accurate sensory systems required for virtual reality systems [152] • Equipment should be worn, or a dedicated room is required for virtual reality systems	• Expensive devices • Need to be programmed

2.1.4 Summary

This section presented the most common physical disabilities of the participants in our studies. CP and SB are two chronic medical conditions present at birth affecting the motor function. SCI and ABI occur after birth and can also cause mobility impairment, and depending on the severity of the injury, palsy might be permanent.

Patients suffering non permanent or permanent injures can recover or improve their quality of life with the appropriate medical treatment. Intensive rehabilitation is the common procedure to recover motor function of the limbs affected by palsy. However, patients' motivation and adherence to their prescribed programme are some of the challenges carers face when delivering rehabilitation, specially with the younger population unable to comprehend the goals of their rehabilitation.

Different technologies such as video games, VR, or social robots have been used to improve patient adherence to their prescribed programme. While video games and VR are useful to complement rehabilitation or intensify physical mobility, they lack the versatility, and cannot easily be adapted to the individual needs of the patient. Furthermore, the goals of the video games might not be aligned with the goals of rehabilitation. Socially assistive robots can overcome some of the issues of video games or virtual reality systems. Thus, the literature review of this thesis will be focused on robots in therapy rather than other alternatives such as video games, or VR. This review also covers robots designed following a relevant design process for this thesis, and evaluation methods for the human-robot interaction.

2.2 Human-Robot Interaction for Paediatric Health Care

This section provides a thorough review of the relevant literature on robots used in health care for the paediatric population. I start introducing the SARs category presenting some of the most common robots used in studies. I also introduce the most common applications for SARs in health care settings for the paediatric population, doing a detailed review of SARs for physical rehabilitation which is the main focus of this thesis. Finally, I summarise the findings of this section.

Even though this thesis is primarily concerned with SARs in therapy, the first robots used in rehabilitation typically focussed on physical assistance during therapy [232]. Thus, a brief review of physically assistive robots is provided below.

Examples of robots using physical assistance during therapy are exoskeletons such as

"Lokomat" [100] and "LOPES" [233], designed to assist lower extremities functioning and gait rehabilitation on a treadmill. Industrial assembly arm robots (such as SCARA) were adapted to assist in the recovery of upper limb mobility [118], and also the haptic device HapticMaster [231] with 3 degrees of freedom has been used to assist upper limb rehabilitation for children and adolescents with CP [58].

Other robots in rehabilitation are assistive devices to help people with impaired mobility with their daily tasks. One of the first assistive robot prototypes for children was Handy 1 [225], a robotic arm with a food tray developed in 1988 to provide more autonomy to an 11 year old child with CP. In further work [226], the system was improved, adding three modular interchangeable trays to assist other tasks such as washing, shaving, teeth cleaning and cosmetic application. Handy 1 was designed to assist activities of daily living, but not in rehabilitation.

Not all robots provide assistance to humans with physical contact. SARs define a category of robots that provide assistance to humans thorough social engagement [53]. Since SARs do not provide physical assistance to individuals, they focus on motivational and coaching aspects providing the appropriate emotional and verbal cues to their users [140]. Thus, SARs are the category of robots most relevant for this thesis in which the aim is to improve child motivation, engagement, and adherence in their recovery programme.

2.2.1 Socially Assistive Robots

As previously introduced, robots that provide assistance to humans only through social engagement are defined in a category called SARs [53]. Those robots are intended to provide users an engaging and pleasant experience while helping them to complete their tasks, or to simply keep users company.

The user population of SARs is not limited to any specific user, however, those robots are in general more suitable for people who require additional assistance [140], examples of those populations are: elderly people [239], children [64], individuals with physical impairments [240], and/or cognitive disorders [181]. The main duties of a SAR are related to the specific needs of their users, some of the tasks are: tutoring [105], physical therapy [143], daily life assistance [30], and to encourage emotional expression [173].

SARs can be shaped in different forms, for example they can be zoomorphic such as the dog-shaped AIBO robot [68], the baby seal PARO [160], or the dinosaur Pleo [96]. Humanoid SARs are also common, exhibiting traits of a human adult such as Pepper [168], REEM [55], and Bandit [240]; or the traits of a child human such as NAO [76], Kaspar [229], iCub [146], or DARwIn-OP [81]. Other SARs are shaped neither as an animal nor a human, for example Keepon [115], Tega [114], Huggable [99], and PETS [48]. Robot designers shape the robot according to the characteristics they want to provide the robot and their context of use, thus, I provide a brief description of some of those robots to better understand which social assistive robots are more appropriate for rehabilitation scenarios.

Zoomorphic or ‘petdroid’ robots are generally designed to assist in the context of pet-style robots for entertainment and companion purposes. Aibo is one of the first autonomous robotic pets which reacts to visual, audio, and touch stimuli [68]. Similarly, PARO [160] is the seal robot covered with fur which actively seeks for eye contact, and reacts to audio and tactile stimuli. PARO has been very popular in aged care centres in order to reduce stress, improve mood, and promote social interaction among elderly residents [28, 72, 109, 155, 238]. Pleo, shaped as 1 week-old baby dinosaur [96], embodies the same principles as the other pet robots: reacts to sound and touch for entertainment and companion purposes. Pleo has been mainly used in studies among children on the autism spectrum disorder [4, 110].

Humanoid robots on wheels such as Pepper [168] and Reem [55] are typically used as service robots. They assist humans to reach specific locations or deliver basic information in museums [44], and in shopping centres [1]. Robots on wheels are not only useful as a visitor information point, the humanoid torso of the robot can also be helpful to assist humans undergoing upper limb rehabilitation exercises such as Bandit [240].

In general, SARs used in rehabilitation have a humanoid body in order to demonstrate the correct execution of the exercises. NAO [76] is a commercially available general-purpose social robot measuring 57cm tall, which has has been very popular in several studies with children. NAO is one of the most common humanoid robots used in the context of paediatric rehabilitation [67, 78, 132, 173, 176, 235], which is the relevant topic in this thesis (discussed in more detail in Section 2.2.4). DARwIn-OP [81] is a humanoid robot with different characteristics and reduced dimensions (46cm) compared to the NAO robot. DARwIn-OP has been less popular than NAO but has also been used to socially assist paediatric rehabilitation [70, 71]. Another humanoid robot, the size of a 3.5 year old child and 1 meter tall is iCub. The motivation behind this open source humanoid robot is to develop a robotic platform for research in embodiment cognition [146]. iCub has been used in different studies, but not for rehabilitation purposes. Humanoid robots are also used to interact with children on the autism spectrum. Kaspar [229] is a minimally expressive child-sized humanoid robot used to learn social interactions. Kaspar, with its simplified human features, has proven to be effective for interaction with children on the autism spectrum.

Keepon is a small yellow non-zoomorphic and non-humanoid teleoperated robot used for non-verbal interaction studies with children. Among other uses, Keepon has been used to interact with children in autism therapy [115]. Robots not shaped in an animal or human form are commonly used to interact with children, for instance PETS [48] allows children to snap different body parts and create their personalised storyteller robot. Tega [114], a small social robot covered in fur, has been designed for long-term interaction with children. For example, Tega has been used as a social companion tutor for children learning a second language [75]. Huggable [99] is a teleoperated teddy bear companion robot used to reduce stress and anxiety by engaging children in fun interactions while they are in hospitals [127].

The non-exhaustive list of social robots presented above includes the most common SARs used for children in health care settings. Below I review the main health care applications for SARs and children. I have identified the following applications: Robots socially assisting children on the autism spectrum; robots helping in play therapy; and the main focus of this thesis which is SARs helping in paediatric rehabilitation.

2.2.2 Socially Assistive Robots in Autism Therapy

The paediatric population on the autism spectrum have been one of the major areas of research for SARs [25, 195]. Findings in the design and evaluation methods of SARs for children with autism spectrum disorders are informative to physical rehabilitation.

The AURORA project was focused on investigating how autonomous robots can act as social mediators for children on the autism spectrum [36]. Mobile robots, Robota [37], or the minimally expressive robot Kaspar [38] are examples of robots used in the AURORA project. Robota was used in a longitudinal study with 4 children during 4 months, where it was observed that in some cases children started using the robot as a social mediator with their teachers [181].

Feil-Seifer and Matarić [54] conducted a study comparing the social interactions of children with autism when operating in one of two modes: robot reacting to children's inputs, and robot selecting a behaviour randomly. They measured social interactions, counting the number of utterances from the child and the parent, the number of child-robot interactions (such as button pushes), and child responses to the robot. The authors conclude that a robot which responds to the child's behaviour evokes more social interaction from the child than the robot which acts with a random behaviour.

A study with children on the autism spectrum and a confederate human assistant used three different interactive aids to elicit social interactions between them [110]. The robot dinosaur Pleo, a tablet interface, and a researcher were used as social mediators. Video recording was used to analyse the social behaviours (utterances) of the child with the assistant. Results indicate that Pleo elicited more verbal statements from the child and social interactions with the assistant than the other interactive aids. The authors suggest that the child's excitement and interest with the robot was the main cause of the increased interaction with the assistant.

Pleo was also used in the PATRICIA project, aiming to reduce pain and anxiety in children while in a hospital [4]. The limitation of the robotic platform experienced by the authors in the PATRICIA project, inspired the researchers to develop their own robotic platform to facilitate learning with children on the autism spectrum [35].

Various different types of robots have been used in this research area of SARs for children with autism, examples are: the minimalistic Keepon [116], the humanoid NAO [215] robot, the low-cost CHARLIE [14], and the hyperrealistic Alice [82]. Even though different robots are used in autism therapy, all the experiments have in common the way to capture data. Experiments with this kind of population are normally video-taped. The data is extracted through post-processing the recordings and annotating the child's interactions with the robot and other participants (gaze, touch, proximity, etc.), and also annotating the participants' utterances, and reactions (laughing, smiling, etc.) [14, 54, 110, 182, 215, 241]. This will be further explained in Section 2.4 evaluation methods for Human-Robot Interaction.

2.2.3 Socially Assistive Robots in Play Therapy

In this section I review SARs used as a complementary part of the rehabilitation where children can play sharing stories with the robot, or freely explore and operate the robot. Examples of play therapy applications are storytelling robots [11, 48, 173] in which children can express their thoughts and emotions; robots to reduce pain and anxiety in children undergoing medical procedures [10, 99, 101, 127, 164]; robots teleoperated by children in order to enhance motor function activity [19, 20, 102, 180]; or robots socially assisting children while participating in other games or activities to complement therapy [70, 71, 91, 117, 213]. Such robots can be used as a complement in the normal rehabilitation programme, and thus the findings in such studies can be informative to the development of SARs for physical paediatric rehabilitation.

Storytelling Robots

Plaisant et al. [173] developed a prototype of a story telling SAR to provide motivation for children undergoing rehabilitation. They used PETS [48] robots which allow children to personalise their own robotic platform by snapping together different modular animal parts. After introducing a story into the system, the robot acts as a story teller reacting with its arms to emotions introduced in the text (sad, happy, etc.). Children can also interact with the robot with two accelerometers attached to their armbands, which are used for the robot to mimic the child's arm movements.

Storytelling social robots have also been considered for use with children and adolescents. The storytelling rabbit robot proposed by Bers et al. [11] was used to interact with 8 patients with serious medical illness in a hospital setting. The robot and the computer controlling it were mounted on a wheeled cart for easy transportation in the hospital. Patients used the storyteller in different modes: to write and record stories, to create conversations, to draw characters and to interact with them. The authors provide recommendations for successfully deploying play kits in hospital environments. Play kits must be able to support interruptions in busy hospital environments. Play kits should allow different kind of inputs for patients with different needs; and play kits must be portable.

Robots in Pain Management

Social robots have also been used to help children who are going through pain, stress and/or anxiety in hospitals. For example, PARO was used as a social companion for inpatients between 6 and 16 years old [164]. The study explored if the use of the robot could reduce pain and anxiety in patients and parents. Patients who participated together with parents were more successful in decreasing pain and negative emotions than patients who interacted individually.

Hospitalized children also interacted with Huggable [99], a teleoperated companion robot shaped as a furry teddy bear to provide new ways to address the emotional needs of inpatients. The robot uses a smartphone for its computational power, and it is teleoperated by a carer outside the room. Forty four children between 3 and 10 years old were randomised in a study with three different conditions: the social robot Huggable; a tablet based version of the social robot; and a plush teddy bear. Children who interacted with the social robot reported more positive emotions and seemed to relax more than children in the other groups [127].

Similarly, the NAO robot was used to help children who received their annual flu vaccination [10]. Fifty seven children around 6 years old participated in a randomised study with two different groups: a standard vaccination session with a nurse; and a vaccination session with the NAO robot using cognitive-behavioural strategies with the child while the nurse is administrating the vaccine. Measures of distress and pain reported by parents, children, nurses and researchers indicated that children who interacted with the robot suffered significantly less pain and distress.

In a later feasibility study [101], NAO was used to reduce pain and distress during subcutaneous needle insertions in children with cancer. Forty children were divided in two groups: the NAO robot using cognitive-behavioural strategies with the child; and the NAO robot dancing and singing during the procedure. The second condition presented less technical difficulties, and distress was less pronounced for children during the procedure.

Teleoperated Robots for Rehabilitation

Leonardo [20] is a robot platform designed to motivate repetitive physical activities such as required in rehabilitation. The system consists of a physical robot and a graphical simulation of it. The robot has the ability to mimic and correct the upper body posture of the participants with a 3D vision-based system. Researchers designed different games, however, no specific population has been defined to interact with the platform. The system has not been tested either with participants or patients.

CosmoBot [19] is a teleoperated robot designed to motivate, play and interact with children in physical therapy. The robot has been tested with children undergoing upper limb therapy sessions. Adapting a similar approach to Bers et al. [11], children can play with the robot in three different modes: Live Play, where the child controls the robot movements and audio output in real time; Record, in which the movements of the child and audio are recorded; and Playback, where the recorded sequences are reproduced. The robot was tested in a study with 6 children between 4 and 10 years old diagnosed with CP. Therapists feedback indicated that the robot is easy to use and motivating. The authors conclude that the motivating aspects of the robot might offer benefits for children achieving their therapeutic goals.

Another teleoperated prototype developed, but not yet tested with patients, is “Neptune” [102], a mobile platform with a 6 degrees of freedom robotic arm to assist rehabilitation of children with motor impairments. Developers provide different devices (Nintendo Wii Remote, iPad, Neural Headset, a camera, and pressure sensors) to interact with the robot in different assistive scenarios, for instance arm positioning with the Nintendo Wii Remote.

Roberts et al. [180] also worked with the concept of teleoperating robots to assist in rehabilitation. The Manoi AT01 robot, with a modification to its hand, provide a open/close behaviour, and was used together with a glove device connected via Wi-Fi to select between different behaviours of the robot. The robot was tested with 20 adults executing different behaviours (such as open/close hand, dance, etc.). Participants in general reported enjoyment controlling the robot in real time. The authors suggest that children can be engaged in doing exercises with the robot due to its perceived enjoyment.

Robots Enhancing Activities that Complement Therapy

An in situ exploratory study to determine potential areas to implement a robot in a hospital environment was carried out in the University of Virginia’s Children’s Hospital. After evaluating the implementation complexity and the estimated impact on the patient population, the authors concluded that three roles for the NAO robot are the most appropriate to implement in a hospital setting: a Cheerleader, a Child-Patient Interviewer, and a Physical Therapy Movement Leader [91].

Similar to the cheerleader role, Kozyavkin et al. [117] used the "KineTron" humanoid robot to engage and encourage children's participation in rehabilitation activities. The authors highlight the existence of potential benefits in an engagement study with children with CP. Six children aged between 4 and 9 years old interacted with the system over 5 to 7 20 minute sessions. Their rehabilitation system also includes computer games and other rehabilitation games such as a dance mat.

VR games have also been used in rehabilitation where a social robot is involved encouraging patients. The humanoid robot DARwIn-OP has been used to engage adolescents when interacting with a VR rehabilitation game to encourage upper-body limb movement [71]. Their pilot study divided 20 adolescents (between 15 and 16 years old) into 4 groups: VR game without the robot, VR game with the robot giving verbal supportive phrases, VR game with robot making gestures, and VR game with the robot doing a combination of phrases and gestures. The group that played the VR game with DARwIn-OP delivering both verbal phrases and gestures rated their experience as more enjoyable and less boring compared to other conditions. DARwIn-OP provided on-line feedback performing the movement according to the predicted movement time (speed) calculated for each participant. Fourteen fully developed adolescents (between 15 and 16 years old) participated in their study, thirteen were able to reach their corresponding movement time following the robot instructions [70].

VR video games together with robots have also been used by other research groups. "Ursus" is a combination of a low-cost robot and augmented reality device to assist upper limb rehabilitation exercises for children with CP [213]. They implemented two different activities: an exercise to mimic the robot doing arm raises, and a VR video game in which patients play using their upper limb extremities.

SARs have been used in play therapy to improve mood and engagement of children and adolescents in rehabilitation. While storytelling robots allow patients to use their creativity to write their own stories [11] or to snap different modular parts of the robot [48, 173], teleoperated robots engage patients through physical activity [19, 20, 102, 180]. The literature also shows that robots can be good motivators for patients doing other activities complementing their therapy such as video games [117] or VR games [70, 71, 213]. Independently of the role of the robot, the common aspect of robots in play therapy is the robot being able to engage patients and make an enjoyable experience.

2.2.4 Socially Assistive Robots in Physical Paediatric Rehabilitation

SARs assisting paediatric rehabilitation is a more recent focus of research, driven in part by the development of affordable humanoid robots and accessible programming interfaces. In the previous section I reported how some robots in play therapy engaged patients in physical activity. However, robots did not guide patients though the prescribed rehabilitation programme, or robots were used as a complement for other activities. In this section, I provide a review of the relevant literature on robots with a social component to assist physical paediatric rehabilitation which is the main topic in this thesis.

Borova et al. [15] are developing the robot “MARKO”, a human-like robot sitting on a horse-like mobile platform. Their intention is to use “MARKO” to assist doctors in paediatric rehabilitation. The robot will motivate children in their physical therapy and demonstrate the execution of upper and lower limb exercises [171]. They propose three different therapy scenarios for children with CP: gross motor skill exercises, fine motor skills (manipulating different coloured and shaped small objects), and speech exercises. The architecture of the robot has been presented but is still pending to be tested with participants or patients.

Vircikova and Sincak [235] used the NAO robot to guide physical therapy for children in a school and in a hospital environment. The robot was programmed to socially assist rehabilitation exercises for spinal disorders. The study was conducted over 2 days, during which time the robot interacted with 50 children aged between 5 and 7 years old. Qualitative analysis of the video recording indicated that participants showed interest in the robot, enjoyment and compliance when doing the exercises.

Fridin and Belokopytov [67] proposed an advanced architecture to assist several children in a rehabilitation session. A rehabilitation scenario illustrated by the authors is the NAO robot asking children one by one to stand up, doing arm raising exercises mimicking the robot, and then asking children to sit-down again. Their preliminary study in a kindergarten with 14 normally developed children and 11 children with CP measured the number of motor tasks completed, and also the child-robot interaction measuring the gaze, speech, and facial expressions. The positive results of their measures indicated that children enjoyed the interaction with the robot, and their feasibility study suggests that assistive robotic platforms can be useful to engage pre-school children in motor exercises.

The use of the NAO robot for rehabilitation has also been proposed by Malik et al. [132] in four different activity scenarios: First, an interactive communication scenario to create rapport between the robot and the patient. Then, they propose three different exercises with the objective to improve lower limb function, including: Sit to Stand, Balancing, and

Ball kicking exercises. The authors suggest that the robot is not appropriate for mimicking walking activities due to its gait [134]. Two patients (aged 9 and 13) diagnosed with CP underwent four activity scenarios (Introductory speech, Sit to Stand, Balancing, and Ball kicking), the patients showed anecdotal improvement in the cognitive and motor function tests (Comprehensive Trail Making Test 'CTMT' and Time Up and GO 'TUG') after interacting once a week during 8 weeks.

The four activity scenarios (Introductory speech, Sit to Stand, Balancing, and Ball kicking) were validated after surveying 30 physiotherapists and occupational therapists [133]. Most of the participants confirm that the activity scenarios purposed are suitable for children with CP, however, some were sceptical about the robot's ability to improve the patient's motor skills aimed in each scenario. Participants also noted the lack of interactive speech of the robot.

Guneysu et al. [80] proposed an off-line procedure to evaluate the performance of a child doing upper body exercises using a Kinect camera. The Kinect is a RGB-D camera that captures depth in addition to the RGB colour, allowing 3D body part tracking. Eight healthy children aged between 3 and 11 years old imitated the NAO robot doing three different exercises. The children's exercise performance was evaluated by the algorithm and also by the attending physiotherapist, and similar evaluation ratings where obtained. In further work [79], the authors replaced the Kinect camera with Inertial Measurement Units (IMUs) attached to the childen's limbs to overcome the issues of physiotherapists occluding the patient in the Kinect captured images. Two patients, 11 and 5 years old, interacted with the robot using the IMUs attached to their arms. The younger patient expressed dislike of having the sensors attached after 5-6 minutes. Further work [78] tested their system with 19 normally developed children. Children participated performing the exercises with the robot, and then filled in a questionnaire at the end of the session. Children responses overwhelming agreed that the robot was good for motivating them to complete the exercises.

Also using the NAO robot to deliver therapy, Pulido et al. [176] developed NAO with enough autonomy to lead physiotherapy sessions without a human operator, and to evaluate the patient's performance. NAO greets and invites the patient to do a set of exercises mimicking the posture of the robot's arms. A Kinect camera (RGB-D) is used to detect the appropriate posture of the patient. They tested their system with 117 healthy school children and 3 patients. Participants interacted once with the robot, and survey data and video analysis indicated that participants were motivated and enjoyed training with the robot. In further work [177], eight patients aged between 3 and 10 years old participated in a 4 month study doing two 30 minute session of rehabilitation per week, in which 2 months rehabilitation was done without the robot and 2 months more with the robot. Sessions with the robot consisted of two exercises (mirror game where the patient mimics the robot, and a memory game in which the patient remembers the previous postures) incorporating entertainment modules along the session. Exercises were adjusted to the needs of each patient, the robot was remotely configured by engineers, and locally adapted if required by the attending therapist. Survey data about the usefulness, satisfaction, and easy of use of the system were collected, together with observational clinical measures for the motor function assessment. Results indicate that the system was useful for engaging patients in their rehabilitation, was easy to use, and participants presented a slight improvement on their motor function.

In most of the recent studies, researchers have used an affordable general-purpose social robot: the NAO robot. The main role of the robot in rehabilitation has been as a coach, where the robot invites patients to go through the exercise programme [132, 235]. Also researchers used the robot to demonstrate the exercises, and accompany the patient providing motivational statements while doing the exercises together [67]. The most advanced systems incorporate external sensors in order to provide real time feedback about the patient's performance [78, 177].

However, most of the research done in this area is proof of concept and does not seem to be further developed for an ongoing clinical setting. While previous work has explored specific roles and functionalities to support paediatric rehabilitation, researchers have not considered a design methodology of such capabilities in the context of ongoing clinical deployment. Most of the design work is lab based, or authors do not specify a design methodology. Addressing this gap is critical to understanding the clinical context that SARs must operate in and for establishing the long-term legitimacy of SARs as effective and usable therapeutic aids with therapists and caregivers.

Table 2.2 provides an overview of the relevant literature presented in this subsection about SARs delivering rehabilitation exercises to paediatric patients. The table summarises the design methodology of the robot, the number of patients, the study procedure, measures, and outcomes of the study.

2.2.5 Summary

SARs have been widely used to interact with different user populations. Children on the autism spectrum are one of the populations that has interacted with SARs for a long time. Studies with this population are normally video-taped, data are extracted through post-processing the videos, annotating the child reactions and interactions with the robot and with people in the study.

Children and adolescents with impaired mobility have taken advantage of new tech-

Table 2.2: Descriptive characteristics of studies using a SAR in physical paediatric rehabilitation.

Authors (year) and reference	**Robot**	**Design Methodology**	**Patients**	**The Study**	**Measures**	**Outcomes**
Borovac at al. (2016) [15, 171]	MARKO	Lab based	Not tested	N/A	N/A	Authors identify three therapy scenarios for children with CP: gross motor skill exercises, fine motor skills, and speech exercises.
Vircikova and Sincak (2013) [235]	NAO	Lab based	Number of patients not specified. Children aged between 5-7 years old.	Two 20 minute group sessions in a school and in a hospital setting doing exercises for scoliosis reduction.	Qualitative analysis of video recording.	Children showed interest in the robot, enjoyment, and compliance when doing the exercises.
Fridin and Belokopytov (2014) [67]	NAO	Unspecified	11 children with CP (9 boys, 2 girls) mean age 5.7±0.6 years old.	Two sessions: first session to build rapport; second session arm raise exercises.	Number of motor tasks completed. Child-robot interaction (gaze, speech, and facial expressions).	Children showed positive emotions, compliance with the robot's instructions, and enjoyed interacting with the robot.
Malik et al. (2016) [132, 134]	NAO	Unspecified	2 children with CP, 9 and 13 years old.	Weekly sessions of 4 activity scenarios during 8 weeks.	Cognitive and motor function tests (CTMT and TUG).	Anecdotal improvement in the cognitive and motor function tests.
Guneysu et al. (2017) [78, 79]	NAO	Lab based	2 children with upper limb motor impairment (2 girls) 5 and 11 years old.	One session doing 5 different upper limb functional activities.	Observations and Inertial Measurement Units (IMU) sensor data.	While children were observed to enjoy the interaction with the robot, the younger one rejected having the IMU sensors attached. Further work with 19 normally developed children indicated the robot was good for motivating to do exercises.
Pulido et al. (2019) [177]	NAO	Unspecified	8 children with upper limb motor impairment, between 3 and 10 years old.	Twice per week during 4 months, the last 2 months with the SAR. 30 minute sessions doing two upper limb exercises with the robot.	Survey data about the usefulness, satisfaction, and easy of use. Observation clinical measures for the motor function assessment.	The SAR is useful for engaging patients in their rehabilitation, and ease of use. Patients showed a slightly improvement on their motor function.

nology devices to increase their motivation and adherence in rehabilitation. In general, adolescents have used video games or VR settings in combination with other technology devices. For example a crank mechanism from a hand cycle [245], a stationary recumbent bicycle [87], exoskeletons [58], and a humanoid robot [70]. In contrast, children participated in more studies where a SAR was only present as an engagement tool [67, 78, 132, 173, 177, 235]. All the reported studies with children suggested that the interaction with the robot itself is the key component to motivate and engage the patient in their rehabilitation.

While randomised controlled trials have been reported for children on the autism spectrum [183], no formal clinical evaluation of the therapeutic benefits of SARs for paediatric rehabilitation currently exists. Controlled trials require a robust robot that successfully integrates with the needs of an existing clinical practice. A thorough search of the relevant literature yielded very few examples detailing the development and integration of SARs into clinical practise. Indeed, there remains little consideration of design methodologies for the deployment of their SAR, which is a key component for the successful integration of the robot in an existing clinical practise. In general, the deployment of the SARs has been focused on the robotic system itself in a lab environment incorporating physiotherapists' advice, but the SARs reported in the literature have not been deployed as part of the ongoing rehabilitation programme of paediatric patients involving all the stakeholders. This is also reflected in the number of patients and rehabilitation sessions performed in those studies. In the next section I review relevant design methodologies for social assistive robots.

2.3 Design Methodologies for Social Assistive Robots

Design methodology or theory puts focus on how systems are designed rather than what is designed [223]. This thesis reports on the design of a SAR to deliver paediatric rehabilitation in a complex hospital setting with the aim of ongoing deployment. In order to develop and integrate new therapeutic technology in an existing clinical practice, the design methodology must be carefully considered. In this section I review relevant design processes and methodologies applicable to SARs, providing examples to motivate the importance of design methodology as a key component of this thesis.

A major contribution of this thesis is: a novel design process emphasising co-design and in situ development and evaluation. Thus, the next subsection reviews SARs designed following related approaches such as Participatory Design; prototypes designed and tested in the wild (also known as In Situ design and evaluation); and studies in the wild using off the shelf robots with its the final users and in the intended place of use.

2.3.1 Participatory Design

Participatory Design refers to a broad range of approaches that seek to actively include key stakeholders in the negotiation of requirements, design decisions, and implementation throughout development [156]. Workshops, mock-up approaches, hands-on design, storyboarding, video prototyping, and customisation are examples of practices used in participatory design [157].

While I do not formally follow a participatory design approach in this thesis, I include key aspects of participatory design such as the inclusion of all the stakeholders in the design process. Thus, I present a summary of the relevant literature on assistive robots developed following this methodology.

While the Computer-Human Interaction (CHI) community have often used this design method [62], the use of participatory design in the robotics context is relatively limited. Examples of its use include Eftring and Frennert [50], who explore the use of participatory design in the development of a SAR for older adults in their home. The study incorporates introductory workshops [63], including representative users in focus groups, employing robot mock-ups to assist with design.

Šabanović et al. [189] also involved all the stakeholders in the design of robots to assist elderly people. Five staff members from a care institution and five older adults participated in the project going through semi-structured interviews and two workshops. The outcomes of the study indicated that older adults have an unmet need which is companionship, also that PARO was the robot who attracted the most participants (staff members and older adults).

In a multidisciplinary project, Chen et al. [30] developed the Willow Garage PR2 robot to assist a person with severe motor impairments. In total they conducted 4 workshops to iteratively design and test their prototype with the intended user and his primary assistant. The authors claim that thanks to the participatory design approach they have been able to make important progress in the design of a useful and usable robotic system. Testing in situ has also helped to overcome real-world limitations for a mobile robotic platform at the user's home.

Participatory design has also been used in other robotics applications. For example, Sharma et al. [200] iteratively developed and evaluated a semi-autonomous wheelchair to allow a single caregiver to move several individuals with disabilities. Their final viable solution, achieved after 5 iterations, exhibited significant differences from the first prototype, and has been able to meet the project's design criteria, with all the iterative cycles provided valuable guidance for the final design.

In the context of the GUARDIANS project [159], in which swarm robots aim to support firefighters in their operations, participatory design has been considered crucial, among other things, due to the firefighters lack of experience with the swarm robots. Researchers used different rapid prototyping techniques for the user interface such as paper prototyping, electronic toolkits, and mock-ups.

Most relevant to this thesis in terms of application, Plaisant et al. [173] employed participatory design concepts in the design of a prototype SAR to enhance rehabilitation outcomes with children. The authors believe that thanks to the participatory design approach their social robot will enhance children's interest and support their rehabilitation experience. PETS [48] is the robotic platform that they use, also developed using participatory design techniques.

Summarising, participatory design has been used to design different kind of robotic applications. Authors have noted significant benefits of frequent stakeholder engagement, in situ development, and iterative testing to successfully deploy their robotic systems. The literature shows that participatory design in early phases of the project has helped to successfully elicit requirements for the project [63, 189, 159], and projects with further development have been able to fulfil the requirements from the final users [30, 200, 173]. However, participatory design requires the active dedication of all the stakeholders, and in some busy environments such as hospital settings, stakeholders are not always available to participate and provide their input. Thus, design methodologies that provide more flexibility should be considered.

2.3.2 Design and Evaluation In the Wild

Designing in the wild, also known as in situ design, is the process of designing and developing new technology in collaboration with the final users and in the same place of its intended use [184]. This is often supported by high level and/or visual programming languages (such as blockly [169]); high level software development kits (for instance Choregraphe [174]); and plug-and-play technologies to assemble different blocks (sensors, displays, actuators, etc.) for example Arduino or Raspberry Pi tool kits.

Related to in situ design is "Evaluating in the Wild", the process of testing new technology or prototypes with the final users of the technology in the intended place of use. In situ studies can capture final users experiences, and can evaluate how this changes over time [34]. Below I present examples of robots designed and evaluated in situ, and their main outcomes.

Museums have been one of the first and most popular places to evaluate service robots in the wild. For example, RHINO gave tours to more than 2000 visitors during 6 days in the Deutsches Museum Bonn [21]; Minerva operated in the Smithsonian's National Museum of American History for 2 weeks [222]; eleven Robox operated during 5 months at the Swiss National Exhibition Expo.02 [202]; and 3 robots (Chips, The Sweetlips, and Joe Historybot) interacted daily over 5 years autonomously without direct human supervision [162]. In all those studies [21, 162, 202, 222], the authors report a high amount of operational hours and participants that interacted with their prototypes.

In a similar context as museums and exhibitions, GRACE and The Roboceptionist were evaluated in the wild at the AAAI 2005 conference in Pittsburg to analyse their social interaction with conference attendees. GRACE approached conference attendees asking for directions [147], while Roboceptionist, a stationary robot, answered people's questions. Researchers' observations during the study challenged their initial design assumptions, providing new ideas to improve the robots' interaction effectiveness [190].

Robot prototypes have also been tested in the home. For instance, 'Minnie', a service robot, went to 7 different homes in a exploratory study about Human Augmented Mapping [94]. Participants were asked to give a "home tour" in order to study their interaction with the mobile robot in a home environment. Doorsteps, narrow passages, and cluttered areas hindered the robot's navigation and influenced participants' ways of interacting with it. A comparative study about dieting also introduced over 6 weeks, a weight loss coach robot at the participants' homes. Forty five people were divided in to three groups (social robot, standalone computer, and a paper log). Results showed that participants using the robot recorded their calorie consumption and exercise for nearly twice as long as the groups without the robot [108]. The authors report that leaving the robot in situ, at the participants' homes, formed a relationship between people and their robots. A prototype service robot to support everyday tasks and to make elderly people feel safe was tested with 18 participants at their home during 3 weeks. This trial carried out in situ, at the participants' homes from 3 different countries: Austria, Greece and Sweden, was useful for the researchers to find out that participants perceived the robot as a toy, and not as a solution for their everyday problems [175].

The AuRoRa project focused on robots for children on the autism spectrum in therapeutical and educational context. Salter et al. [191] moved from the lab to a school to investigate how infrared sensors on a robotic platform can be used to detect and distinguish human interaction in natural noisy environments. They reported that the technique used in the lab setting was still reliable in the wild, but the data was not as clear due to the noise in the natural environment, emphasising the importance of in situ testing.

The service Robot CERO was used in an office environment to assist a partially mobility impaired user over 3 months [92]. The authors noted that experimenting with the robot in the wild helped to identify important factors not considered previously during the design. For example, limitations of the office environment such as office doorsteps, or bystanders engagement delaying the delivery missions of the robot. In another office environment within a hospital, a mobile robot was introduced to deliver items to selected locations by the employees. Siino et al. [203] studied how the gender segregation of the office environment impacted on the so called sensemaking process (i.e. the social process where people make sense of situations and events [242]) after the introduction of the robot. While male engineers and administrators generally perceived the robot as a new machine to control, female workers were more likely to anthropomorphise the robot as a human male that acted independently. This ethnographic in situ study identified that what could be considered a gender-neutral object such as a delivery robot, was perceived differently by individuals with different gender but in the same working environment.

The introduction of 7 autonomous delivery robots to serve 9 hospital units, trialled over 15 months, generated a wide divergence of opinions among participants with respect to acceptance, including some conflicts in the working environment [158]. The robot altered the usual workflow, causing less work for some, while increasing work for others. Staff in medical units (such as oncology and post-natal units) also had a wide divergence of opinion as to the benefits of the system. Observations and interviews showed that the oncology unit workers who have more emergencies, interruptions, and more stress, perceived the robot as annoying, with limited capability, and expressed willingness to damage it. Conversely, workers within the post-natal unit were happy with the robot, and blamed the supply units for the robot delays. The main complaints of the workers were: the robot interrupting other priority tasks; the increased workload in some units; the pressure from the management team to use the robot; robot breakdowns, collisions, and rudeness in busy corridors.

In another work office environment, a robot to manage break times for office workers was evaluated in the wild as part of three different design steps [237]. The first step consisted of an initial exploration of the office environment, and the construction of a basic prototype with little functionality to get the initial feedback from users. The second design iteration validated the importance of the robot's physical presence by comparing with a virtual robot. Finally, the third iteration evaluated a simple alarm robot versus a robot with more social behaviour. Evaluating the robot in the wild provided early feedback about the robot design, and participants' problems with the technology. However, participants in general gave more feedback about prototype failures, rather than about design factors.

In conclusion, designing and evaluating prototypes in the wild has been very beneficial for robotics developers in different aspects. Authors have reported thousands of participants interacting with their prototypes in museums or exhibition centres [21, 162, 202, 222]; they found issues not considered previously during the design process [92, 147, 175, 190]; or in their lab settings [94, 191]. Finally, one of the most relevant examples for the need of a proper design process is the conflicts generated when introducing robots in a hospital environment [158].

2.3.3 Off-the-Shelf Robots in the Wild

Previously I have reviewed robots designed and evaluated in the wild. In this subsection I report on off-the-shelf robots used in in situ experiments. The main difference with the previous subsection is that researchers do not develop or prototype their own hardware in the wild, but rather develop software and perform studies with commercially available robots in the wild. How researchers have conducted experiments outside lab settings, their learnings, and the difficulties experienced in uncontrolled scenarios with real users will also provide useful insights for this thesis.

The commercially available robot REEM was used in a group-robot interaction experiment at the science museum of Barcelona during a week [44]. The tasks of the robot included informing, giving directions, and walking visitors to requested locations. Researchers reported design issues when bringing the robot into the wild such as children unnecessarily pushing the emergency button requiring manual restart of the robot, children jumping into the rear platform of the robot not designed for carrying people (which has a maximum workload of 30kg), and people getting frustrated after a few attempts to make it work because the robot was being overcrowded by people and could not move.

Several studies have used the vacuum cleaner robot Roomba to study the Human-Robot interaction at the participants' homes. A study over 4 months explored how the introduction of the cleaning service robot changed the participants' habits of house keeping, the participants' relationship with the environment and with others within the environment [60]. A comparative study with 6 families introducing either a Roomba or a regular vacuum cleaner showed that the social attributes of the robot did change the cleaning family habits compared with the addition of a regular vacuum cleaner [59]. For instance, elderly users changed from planned to opportunistic cleaning, and men and children took an active role in cleaning. The Roomba robot was also used in a study of novelty factor, the people's engagement with the service robot just for being new. Researchers ran the study over 6 months, they noted that performing studies at participants' home adds the difficulty of capturing reliable data without invading the participants' privacy [214]. All these three studies with the Roomba robot at the participant's home used semi-structured interviews in order to collect the data [59, 60, 214].

PARO is an example of how a robot with simple functionalities and well targeted design can have high impact in human-robot interaction. Few researchers have studied the benefits of the seal robot in the wild. Wada et al. [239] conducted a study during 5 weeks showing good results with PARO improving mood, reducing stress, and encouraging elderly residents to socialise at an aged-care service centre. In subsequent work over a one year study at the same facility [238], observations from nursing staff, as well as recording on the Geriatric Depression Scale [247], and Face scale [128] confirmed that the interaction with PARO improved the patients' mood and reduced depression. Kidd et al. [109] did a similar study over a period of 4 months with PARO and My Real baby doll in two different nursing homes: in one home, people with high-functioning cognitive ability, and in the other with people diagnosed with schizophrenia or dementia. Another study with 4 patients with cognitive and behavioural diseases was carried out in a nursing home during 3 months [72], observations from video recordings indicated that PARO acted as a social mediator and participants progressively increased their relations with each other. Also 18 participants diagnosed with dementia participated in a study in Queensland during 5 weeks interacting 3 times per week with PARO [155], different measures (such as Quality of Life in Alzheimer's Disease, Rating Anxiety in Dementia, Geriatric Depression among others) indicated that PARO had a moderate positive influence on participants' quality of life when compared with the control group. Focusing on observational findings, Chang et al. [28] observed during 8 weeks how the behavioural patterns (such as stroking, speaking, etc.), the context, and the personal factors of 10 participants with dementia contributed to the PARO's therapeutic effectiveness. PARO has been developed since 1993, it became commercially available in 2004 which is the 8th generation of the robot [219].

Running experiments with off-the-shelf robots in the wild has the advantage that the studies are more repeatable. For instance, PARO has been a great success in the wild for its companion purposes with elderly people [28, 72, 109, 155, 238, 239]. However, PARO took 8 generations and more than 10 years of development before became commercially available [219]. Off-the-shelf robots with less development iterations, or not developed or tested in situ, have been affected by design decisions that have impacted negatively when robots went to the wild [44]. This suggest again the need of designing and testing robots in situ. However, studies with robots in private environments like homes brings challenges in order to collect data and preserve participants' privacy [59, 60, 214].

2.3.4 Summary

The findings when evaluating robots and their interaction with humans in a lab environment cannot always be extrapolated into the real world [184]. Experiments in a lab setting, while useful for establishing controlled conditions, do not capture the real-world conditions under which many robots are intended to be deployed. Variations such as room configuration, lighting, sound, as well as variations between users of the system can all impact significantly on the system's effectiveness. Therefore, studies in the wild can be more revealing than studies done in labs.

The inclusion of key stakeholders is crucial in multidisciplinary projects due to the technology developers lack of expertise in different areas such as firefighting [159]; or in the context of this thesis, due to the lack of knowledge in physiotherapy.

In the paediatric rehabilitation field, there are few examples in the literature about robots designed taking into consideration the design methodology. Storytelling robots in the late 90's were used for in situ studies in hospital environments. However, the rejection of deployed autonomous delivery robots by hospital staff [158] is an indicator of the need of in situ design and in the wild evaluation methodologies.

Some factors that can influence in the context of a SARs delivering paediatric rehabilitation are: type of patients, patient fatigue, physiotherapists, existing clinical practices, hospital environment, limits of the technology, etc. Therefore, it is crucial to consider the working environment and operating context which cannot easily be replicated in a lab environment.

In situ studies also present some challenges. Examples are: the exposure of system failures to the final users, or the compromise between collecting data and preserving participants' privacy if running experiments in private environments.

2.4 Human-Robot Interaction Evaluation

Feedback from health professionals, patients, and parents is decisive for the successful deployment of new technology integrated in a hospital environment. This section reviews the most common methods used to evaluate users' experiences when interacting with SARs.

Researchers have been using a broad range of different assessment methodologies to evaluate the Human-Robot Interaction in their studies [204]. Those methodologies range from methods adopted from Human-Computer Interaction; through Technology Acceptance Models, for instance the "Unified Theory of Acceptance and Use of Technology" (UTAUT) [234]; to analysing more social factors such as the level of users' empathy [120], friendship [103], or user-robot personality matching [3].

Human-Robot Interaction evaluation can be classified in 4 different categories: Self-report measures; Behavioural measures; Psychophysiological measures; and Task performance [12].

2.4.1 Self-report Measures

Self-reporting is one of the most common methods due to its simplicity [107]. Participants report via surveys or questionnaires during or after taking part in the study, thus making the process of collecting data very simple. The data is analysed statistically in order to obtain the results of the participants' perceptions of the robot, for example calculating the mean and standard deviation of the quantitative item responses. Generally, the statistical analysis of the data is not complex which facilitates the extraction of the results.

However, self-reporting also presents some issues. The design of the survey has to be reliable, provide consistent results over time, and also questions should be clear and easy to understand to prevent misinterpretations [77]. Another of the main problems of participants self-reporting is the validity of the data. Participants might answer the questions considering what researchers expect to say, and not their real perceptions [204]. Hiding the intentions of the questionnaire, redundant questions, and combining different evaluation methods are possible solutions to validate the data gathered. The appropriate handling of missing data from the survey responses is also another limitation [45].

Researchers in the Human-Robot Interaction community often design their own surveys for their studies, which complicate the comparison of their results among other studies. To address this, some researchers have been working on establishing common metrics to evaluate their studies [22, 211]. Several authors have designed and validated different questionnaires. Nowadays, the Godspeed questionnaire [8] is the most widely used in the HRI community. However, some inconsistencies have been found in the questionnaire, thus different authors have provided their alternatives [27, 88]. The Acceptance questionnaire proposed by Heerink et al. [85] is another example of evaluation method used in the HRI community. Most recently, the Robotic Social Attributes Scale (RoSAS) [27] has been proposed to evaluate social attributes established in the social psychology literature. As these questionnaires inform evaluation techniques applied in this thesis, I outline each of these questionnaires below.

Godspeed Questionnaire

The Godspeed questionnaire proposed by Bartneck et al. [8] aims to provide a standardised and validated measurement tool to evaluate the user's attitudes towards service robots. It consists of 23 semantic differential scale items, from which participants choose where their position lies between two opposite adjectives. For example:

```
Rate your impression of the robot on the scale:
Unkind      1      2      3      4      5      Kind
```

The questionnaire aims to measure the users' perceptions of the robot in 5 different categories:

1. **Anthropomorphism:** measures the human traits, human characteristics and behaviours of the robot with 5 different items: Fake - Natural; Machinelike - Humanlike; Unconscious - Conscious; Artificial - Lifelike; Moving rigidly - Moving elegantly.

   The appearance of a robot should match its capabilities to not generate false expectations. If a highly anthropomorphic robot does not behave like a human, it could cause rejection due to the so called "uncanny valley" [153].

2. **Animacy:** this category is composed of 6 items which attempt to measure the extent to which participants perceive the robot being alive. Reactions of the robot, its physical behaviour, and communication skills are attributes assessed as part of this measure.

   Items include: Dead - Alive; Stagnant - Lively; Mechanical - Organic; Artificial - Lifelike; Inert - Interactive; Apathetic - Responsive.

3. **Likeability:** this category tries to measure the participants' positive impressions, in terms of the amount of like or dislike they have for the robot. Five different items are included in this category: Dislike - Like; Unfriendly - Friendly; Unkind - Kind; Unpleasant - Pleasant; Awful - Nice.

4. **Perceived Intelligence:** How participants perceive the robot being knowledgable and skilled for its duties is measured in this category. The following 4 items attempt to measure the participants' perception of the robot being intelligent: Incompetent - Competent; Ignorant - Knowledgeable; Irresponsible - Responsible; Unintellegent - Intelligent; Foolish - Sensible.

5. **Perceived Safety:** three items compose the participants' perceived safety category asking participants about their emotions: Anxious - Relaxed; Agitated - Calm; Quiescent - Surprised.

The authors recommend to mix all the items of the questionnaire, and add some dummy items in order to mask the intention of the survey. The validation of the data collected is done by calculating the internal consistent reliability of the 5 different categories. Cronbach's alpha [218] provides a measure of internal reliability, it reports using intercorrelations if the items of the construct measure the same concept. The calculated alpha is a value between 0 and 1, an alpha of 0.7 or above is considered acceptable. The value of the alpha will increase if the items of the category are correlated, however the length of the test and the sample size are other factors that affect the value of the Cronbach's alpha.

More items in a category can help to increase the Cronbach's alpha, a small sample size can reduce it.

Different studies considering different applications have used the Godspeed questionnaire or parts of it. For example: Kanda et al. [104] in a study with a teaching assistance SAR for children measured, among other aspects, the likeability of the robot using the Godspeed scale. The likeability construct successfully passed the reliability test, and the robot in the social behaviour condition was rated more likeable than in the non-social behaviour.

Participants were asked to rate the perceived intelligence of their vacuum cleaning robot Roomba in a long term study [56]. The authors adapted the perceived intelligence construct of the Godspeed questionnaire, with results indicating that the robot was perceived only somewhat intelligent because the robot was able to clean, but not able to perceive where dirt was present, and sometimes left areas without cleaning.

Foster et al. [61] used the five constructs of the Godspeed questionnaire in their study with a bartender robot. All the constructs successfully passed the reliability measure, with Anthropomorphism and Animacy being the constructs that were rated the lowest. Results indicate that the two manipulator arms of the robot were not perceived as very human-like, interactive or animated. The authors suggest that future studies should only use the relevant constructs for the study in order to reduce the survey items.

Schneider and Kümmert [197] also used the 5 constructs of the Godspeed questionnaire in their study with the NAO robot to promote exercise. Fifty six participants (university students) exercised in one of the 3 different conditions: without robot, with robot instructor (robot observing how participants do the exercises), and with robot companion (robot doing the exercises together with the participants). The robot companion condition was rated significantly higher in the Likeability and Animacy constructs, suggesting that the robot companion role was perceived more interactive and alive, thus more enjoyable than the other conditions.

In another study doing physical exercises, the full Godspeed questionnaire was used to compare between two different conditions: an embodied physical robot, and a video projection of the robot [125]. Twenty three participants took part in both conditions and rated the embodiment robot slightly higher in all the categories.

Godspeed Questionnaire Critique

While the Godspeed questionnaire has been widely used, several researchers have indicated issues with the instrument. Ho and MacDorman [88] for example, conducted an empirical analysis of the Godspeed questionnaire as measures of human likeness with 384 participants rating animated-computer characters and robots from videos. The authors found several issues with the consistency of the questionnaire:

- Perceived Safety category did not pass the internal reliability measure Cronbach's alpha [218], not reaching the required 0.7 threshold. This indicates that items in the Perceived Safety category might be measuring different aspects.
- Confirmatory factor analysis showed that several semantic differential items did not fit well in the five category division of the questionnaire, indicating that there are items which do not represent the constructs they are evaluating.
- There is an extremely high correlation among Anthropomorphism, Likeability, Animacy, and Perceived Intelligence, suggesting that those categories have significant overlap in what they are measuring.
- The anthropomorphism category could not classify robots by their degree of humanness.

Therefore, the authors modified the questionnaire in two testing rounds. They included new variables to cover the so called "uncanny valley" [153], in which a robot's appearance approaches but does not quite achieve a natural look, leading often to negative reactions. They developed the Attractiveness, Eeriness, Humanness, and Warmth categories to evaluate the animated-computer characters and robots.

Generally, Ho and MacDorman's questionnaire has been used in studies related to the uncanny valley hypothesis [153], rather than in studies of participants' perceptions of a SAR. For example, Mitchell et al. [150] in a visual-auditory experiment studied the levels of eeriness when mismatching a human and a robot with a synthetic and a human voice. Results show that the mismatching condition increased the levels of eeriness, indicating that the human realism of a robot should also match to its voice.

Studying whether different walking patterns of a robot (happy natural walk, happy exaggerated walk, sadness natural walk, sadness exaggerated walk) have an effect on people's perceptions of naturalism, Destephe et al. [42] found that the participant's attitude towards the robot is the main cause of the uncanny valley effect rather than the walk pattern.

In a VR chat setting, Stein and Ohler [210] also used Ho and MacDorman's questionnaire in a study with 2 digital characters having an emotional and emphatic conversation. Ninety two participants were divided in 4 different conditions altering the perceived control type of the avatars, and the level of autonomy: human-controlled avatars with scripted dialogue, human-controlled avatars with autonomous dialogue, computer-controlled avatars with scripted dialogue, and computer-controlled avatars with autonomous dialogue. Results showed that the computer-controlled avatars with an autonomous emotional and emphatic dialogue had a significantly higher level of eeriness. This indicates that virtual creations that can act similarly to humans can awe people.

Along the same lines as Ho and MacDorman [88], Carpinella et al. [27] analysed the Godspeed questionnaire and found some inconsistencies. The Godspeed scale tries to measure 5 different and unique dimensions when judging social robots. However, they found that the items fall mostly into 3 different categories: Animacy, Perceived Intelligence and Likeability.

The RoSAS scale was presented by Carpinella et al. [27] in 2017 with the aim to complement the Godspeed questionnaire. Based on attributes from the literature on psychology research, particularly that focused on social cognition, and the outcomes of a second study they generated 18 items classified in 3 different categories: Warmth, Competence, and Discomfort [27].

This thesis is focused more generally on the participants' perceptions of the SAR rather than focusing on the uncanny valley hypothesis. The Godspeed questionnaire has been extensively used in more HRI studies making the questionnaire more attractive in order to compare among different study results. In light of the reported limitations of the Godspeed questionnaire, in this thesis we place special attention on how we use this survey.

Acceptance Questionnaire

The Acceptance questionnaire proposed by Heerink et al. [85] is an adaptation of the Unified Theory of Acceptance and Use of Technology (UTAUT) model [234], which measures the users' acceptance of new technology. The authors aim to evaluate the acceptance of social robots, in particular for the demands of elderly users.

The questionnaire is composed of 41 items using the Likert scale form. Each item asks a question allowing the participant to provide their level of agreement from Strongly Agree to Strongly Disagree. For example:

```
I think it's a good idea to use the robot:
Strongly Disagree   1   2   3   4   5   Strongly Agree
```

Twelve different constructs comprise the questionnaire, each construct has between 2 to 5 items. I describe them below.

Anxiety: measures emotional reactions when using the robot such as being afraid of the robot, or being afraid to damage it.

Attitude: measures the user's stance on the use of the robot for the considered application.

Facilitating Conditions: measures to what extent the user feels they have all they need to use the robot effectively.

Intention of Use: measures the extent to which the user plans to use the robot voluntarily in the near future.

Perceived Adaptability: measures the extent to which users consider the robot is able to adapt to their changing needs.

Perceived Enjoyment: measures the extent to which the users enjoyed interacting with the robot.

Perceived Ease of Use: measures complicated or how much effort was perceived or was required by the participants in order to use the robot effectively.

Perceived Sociability: measures the extent to which users perceived the robot as socially engaging.

Perceived Usefulness: measures to what extent users considered the robot useful when assisting them.

Social Influence: measures how much social pressure was perceived by the users to use the robot in their workplace.

Social Presence: measures the degree to which users perceive the robot as being present during the interaction.

Trust: measures to what extent users perceived the robot as reliable and trustworthy to receive advice from.

The data collected for each construct should be validated by calculating the internal consistent reliability using Cronbach's alpha [218]. The authors of the questionnaire report an example using the survey to evaluate the acceptance of the iCat robot connected to a touch screen to interact with elderly users. All the constructs successfully pass the reliability measure. Also the authors report the inter-dependencies of the different categories, for example: "Perceived Ease of Use" and "Perceived Enjoyment" influence the "Intention to Use". Another example of interrelations in the questionnaire was explored in a study with a companion robot for the elderly [86]. The lack of social abilities of the robot negatively affected the Social Presence construct which also affected the participant's Perceived Enjoyment.

The questionnaire can be reduced by eliminating different categories if researchers just want to focus on specific parts of the model. Below I list examples of different studies using the Acceptance questionnaire, or adaptations of it.

Fridin et al.[65] evaluated the acceptance of the NAO robot by preschool and elementary school teachers using 11 of the 12 questionnaire constructs (not including the

Perceived Ease of Use). Results suggest the robot was accepted by the teachers, and also reflect a strong correlation between Intention to Use and Perceived Usefulness.

Depending on the objectives of the study, researchers have combined parts of different surveys (such as the Godspeed and the Acceptance questionnaires). For example, Kanda et al. [104], in their study with a teaching assistance robot for children, combined the Likeability category of the Godspeed questionnaire with the Perceived Enjoyment and Intention to Use from the Acceptance questionnaire. The two categories of the Acceptance questionnaire also passed the reliability measure Cronbach's alpha. The robot in the social behaviour condition was also rated more enjoyable and children reported more intention to use it.

The long term study with the vacuum cleaning robot Roomba also combined constructs from the Godspeed and the Acceptance questionnaire [56]. Researchers used the Perceived Usefulness and Perceived Ease of Use constructs from the Acceptance questionnaire. Participants found the robot very easy to use and quite useful, however perceived usefulness decreased over time.

A modification of the Acceptance questionnaire was used in a study with a robotic toy box which encourages children to tidy up their room [57]. The robot had two different behaviours: proactive in which the robot seeks toys and gestures in front of the toy so the child can put it inside the robot; and reactive where the robot only reacts when a toy has been placed inside. Among other measures, parents filled in the modification of the survey to measure 8 of the 12 constructs: Perceived Ease of Use, Perceived Usefulness, Anxiety, Attitude, Intention to Use, Perceived Enjoyment, Perceived Sociability, and Social Presence. Results of the Acceptance questionnaire indicated that parents found the robot easy to use, useful, and liked the idea of having the robot.

Capturing data when doing studies with children can also be challenging, for example young children might not have sufficiently advanced cognitive function to fill in a survey, thus alternative methods might be required. Primary school children participated in an in-the-field study at their school [83]. Researchers used the Pleo pet robot to evaluate how children perceive and interact with the robot. The authors report that self-report measures (such as questionnaires) and behaviour observations are valid complementary methods to evaluate the children's experience with the robot.

2.4.2 Behavioural Measures

Behavioural measures are data gathered from participants' activity (movements, gaze, speech, gestures, etc.) during their participation in a study [39]. It is a common method used with very young participants [64], participants on the autism spectrum [216], or in studies focused on the human interaction patterns with a robot [224] to support symbiotic systems with humans and service or industrial robots [139]. Normally, the study is video-tapped and post-processed to measure quantitatively and/or qualitatively the participants' "micro-behaviours", low-level movements, or actions.

Fridin et al. [64, 66, 67] developed a method to measure, from observations, the interaction level of young children with a robot. They classify the interaction level in two different categories: eye contact, and emotional factors which includes utterances, body, and facial expressions.

A similar approach is used by Pulido et al. [176] in their evaluation of the NAO robot to socially assist rehabilitation for children (as discussed in Section 2.2.4). From video recordings of their sessions, they capture the level of interaction encoded in 4 different categories: emotions, attitude, gaze, and communication. The interaction levels extracted from the video recordings support the data collected from the questionnaires, and researchers' observations.

Behavioural measures are very common in HRI studies with children on the autism spectrum [14, 54, 110, 182, 215, 241] (studies explained in more detail in Subsection 2.2.2). Studies are typically video-taped and researchers analyse the interactions of the child with the robot, with other participants, and with researchers. The child's emotional reactions such as laughs, smiles, excitement, anger, etc. and the child's micro-behaviours like gaze, touch, proximity, verbal utterances, etc. are coded for data analysis.

Researchers have also combined behavioural measures with self-report measures. For example, apart from using a modification of the Acceptance questionnaire, the study with the robotic toy box that encourages children to tidy up their room also video-taped the participants' interactions with the robot [57]. The authors coded different behaviours, for instance: exploration (child observing the robot), misusage (climbing on the robot, or kicking it), removing a toy, putting a toy, gestures towards the robot, touching the robot, and playing with the robot (petting it, or showing toys). Observational data indicated that almost half of the time children were observing/exploring the robot; and almost half of the actions were putting and removing toys in the robot. The reactive condition of the robot was more effective for the purpose of tidying up the room, whereas the proactive condition prompted more exploratory and misuse actions.

Behavioural measures are crucial among participants who are not cognitive enough to comprehend and fill in a survey or questionnaire. However, it also presents some challenges, for example: ethics for recording in clinical environments such as hospitals; the time required to process the videos; and the Hawthorne Effect [142] in which participants behave differently because they are aware that they are being observed.

2.4.3 Psychophysiological Measures

Measuring human body reactions such as electro-dermal activity (galvanic skin response), skin temperature, cardiovascular responses, blood pressure, respiration, or even brain responses are other methods used to determine the emotional state of a person. Such methods have also been applied in human-robot interaction studies to detect participants' reactions [12, 46]. One of the main advantages of these methods are relative objectivity of the data compared with self-report measures as participants cannot easily hide their body reactions.

Examples include: Mower et al. [154], who were able to identify the user's engagement state when playing a wired puzzle game guided by a robot measuring the galvanic skin response and temperature. An industrial arm robot performing different motion strategies (safe path method, and a potential field method which is considered less safer) was used in a study to evaluate participant's reactions measuring the heart rate and skin conductance response [119]. Participants were sitting next to the robot during the execution of the motion task. Results indicate that subjects were less anxious and surprised with the safe planner.

Liu et al. [126] were also able to successfully detect anxiety using psychophysiological measures. Their robotic coach was able to alter the difficulty of the basketball game depending on the anxiety levels of the participants.

Itoh et al. [97] developed a bioinstrumentation system in order to objectively evaluate the psychophysiological effects of robots on the human. The bioinstrumentation system measures cardiovascular responses, respiration, heart rate, perspiration, and arm motion. After few improvements of the prototype, the third version of the system also includes Inertial Measurement Units (IMU) and extends the sensors to the whole body [199]. The aim of the authors is to measure the physical and psychophysiological effects of the rehabilitation.

Psychophysiological measures have been used successfully to measure participants' anxiety [119, 126] and engagement [154] when interacting with a robot. However, this kind of measure requires specialised equipment [46] and sensors attached to the participant's body in order to capture the raw data [199]. This makes this approach not suitable for many real-world scenarios [107] such as the busy hospital setting of this thesis, or with young patients who might reject having sensors attached to their body [79].

2.4.4 Task Performance

Task performance measures aim to analyse the set of activities and behaviours related to the accomplishment of a task. In the Human-Robot Interaction field, it evaluates how humans and robots work together in a team doing collaborative tasks. Robots with different levels of autonomy, from teleoperated or totally autonomous robots, working with a single person or a group of people to archive a skill or task. For example, Urban Search and Rescue tasks [49] where robots are used to locate victims in post-disaster missions.

Task performance used to be evaluated using metrics focused on the robotic system or on the human performance independently, without considering human-robot interaction metrics [23]. Steinfeld et al. [211] proposed common metrics to evaluate human-robot collaborative tasks independently of the autonomy level of the system, from pure teleoperation to fully autonomy systems. The metrics are divided in three categories: System Performance (effectiveness, efficiency, mixed-initiative, etc.); Operator Performance (situation awareness, workload, etc.); and Robot Performance (self-awareness, human-awareness, autonomy).

Task performance metrics are normally used in robots that perform missions rather than SARs in rehabilitation scenarios. For example, mobile robots being supervised by one or more operators [230], robots used for urban reconnaissance, research and rescue tasks [49, 129], or firefighting operations [159]. It is not easy to find examples of SARs evaluated using task performance methods. If we consider that a social robot assisting rehabilitation exercises to a patient is a collaborative task, task performance will also require evaluation of the patient's execution of the exercises. Task performance measures are not the most appropriate methods to evaluate the human-robot interaction in the context of this thesis.

2.4.5 Summary

Different methods can be used to evaluate a robot delivering therapy for paediatric rehabilitation. The ultimate method is a randomised clinical trial to evaluate how well a patient recovers measuring rehabilitation outcomes. However, it is argued in this thesis that before the clinical trial we need to evaluate how well a SAR is accepted and integrated in a clinical setting to deliver rehabilitation. Thus, it is important to use evaluations methods typically used in human-robot interaction studies.

Self-report is one of the most common evaluation methods used in human-robot interaction studies [107]. If participants do not have the cognitive ability to comprehend the survey, other approaches can be used such as behavioural measures. Video taping patients in hospital settings can bring ethical concerns. Alternatively, researchers can take observation notes of participants' reactions and behaviours, but some of the reactions will be missed. Other evaluation methods used in HRI studies involve psychophysiological and task performance measures. However, psychophysiological measures are difficult to apply in real world scenarios where sensors have to be attached to the participants' bodies, and task performance measures are used for robot missions rather than SARs in a collaborative rehabilitation setting.

In this thesis I am interested in the integration of a SAR for ongoing clinical deployment. As reported by Mutlu et al. [158], the integration of robots in critical contexts such as hospital settings can have a strong rejection from the final users. Thus, one of the priorities of this thesis is to evaluate the acceptance of the robot in its clinical setting. Even though the Acceptance Questionnaire [85] has been designed for the elderly care context, it can be adapted to evaluate the SAR delivering paediatric rehabilitation. The Godspeed questionnaire provides different measures to gauge the participants' perceptions of SARs, for example the perceived intelligence or likeability. Although issues have been reported when using the Godspeed questionnaire [88, 27], it can bring different and relevant measures for our study. Given the popularity of this questionnaire in human-robot interaction studies, it will also provide common measures for comparison among other studies.

2.5 Summary

In this chapter I have reviewed the most common physical disabilities affecting patients who participated in the studies of this thesis. For instance, CP, which is the most common disability affecting mobility and motor function of children. Patients suffering physical disabilities can improve their quality of life, and be empowered to live independently following the appropriate medical treatment and rehabilitation. However, rehabilitation presents several challenges such as children not adhering to their prescribed programme for not being able to comprehend the importance of rehabilitation. Different technology devices, such as SARs, have been used to motivate patients in their rehabilitation programme or to enhance patients' physical activities.

I have reported how social robots have interacted with different paediatric populations in health care. For instance, children on the autism spectrum, or the main application of this thesis: SARs in physical paediatric rehabilitation. While authors have reported promising results of robots to motivate patients in their prescribed rehabilitation programme, little consideration has been given to the design methodologies for the deployment of the robots. I argue that the lack of robust social robots in physical paediatric rehabilitation integrated in hospital settings for ongoing clinical deployment is driven in part for the lack of consideration of an appropriate design methodology encompassing stakeholders' needs in the intended place of use.

Therefore, I have reviewed relevant design methodologies for SARs arguing pros and cons. Participatory design actively involves all the stakeholders through all the design process, which is crucial in multidisciplinary projects. However, the active dedication of all participants cannot always be possible, for instance in busy environments such as hospital settings. In situ design is a more flexible approach which emphasises the development and testing of the new technology in the intended place of use with the final users. The next chapter (Chapter 3) presents the in situ design methodology for SARs in clinical settings.

The ultimate evaluation method of a SAR in paediatric rehabilitation is a randomised clinical trail to evaluate how well patients recover using the robot. However, before the clinical trial, a robust robot accepted by all stakeholders and integrated into existing clinical practice should be evaluated. I have reviewed in this chapter the most common evaluation methods for human-robot interaction studies, being self-report and observational methods the most suitable for our approach. The participants' evaluation of the developed SAR prototype in this thesis is presented in Chapter 5.

Chapter 3

An In-Situ Design Process for Socially Assistive Robots

The previous chapter reviewed relevant literature to contributions of this thesis, in which seeks to design and evaluate a Socially Assistive Robot (SAR) as a therapeutic aid for paediatric rehabilitation. While previous work has explored specific roles and functionalities to support paediatric rehabilitation, few have considered the design of such capabilities in the context of ongoing clinical deployment. As argued in Chapter 2, this remains an important gap in the literature. The design of software and interactive capabilities for SARs must be carefully considered in the context of their intended clinical use.

This chapter presents a design process and evaluation methodology, developed as part of this thesis, for the adaptation of the general-purpose humanoid social robot NAO as a socially assistive rehabilitation aid for children with Cerebral Palsy (CP). Focused on the needs of large scale clinical deployment, key requirements for a SAR operating as a stand-alone therapeutic aid for ongoing use in a clinical setting are outlined. The chapter presents present a three-phase in situ design process, including both exploration of roles and requirements, from which a base-level stand-alone prototype system has been derived.

To my knowledge, this is the first design process for a SAR for rehabilitation that explicitly incorporates patients, carers and therapists in the design process, and is focussed on the design of roles and capabilities for ongoing use in a clinical setting. Later chapters show how this design process has led to a prototype deployed in weekly therapy sessions, leading patients predominantly with CP through prescribed exercise programmes of up to

30 minutes without engineer intervention. It is argued that the design methodology outlined in this chapter has wider applications, in particular to the design and development of SARs, for clinical settings in general.

This chapter is structured as follows. Section 3.1 outlines the in situ design methodology, listing derived roles and requirements for the system from Phase 1 of this process. Section 3.2 and Section 3.3 provide a technical overview of the prototype system deployed in Phase 2 development, and key design choices and considerations. Section 3.4 provides an overview of the testing setup, and the data collected which informed the improvements on the prototype. A summary concludes this chapter in Section 3.5.

3.1 Design Process

From the relevant design methodologies reviewed in Chapter 2, it was reported that Participatory Design seeks to actively involve all the stakeholders through all the stages of design process. However, such formal design processes are difficult to apply in busy and highly dynamic settings such as hospital environments. In situ design is an approach emphasises the development of the technology in the intended place of use with the final users.

Due to the complex and dynamic operational context of the hospital setting, in situ design evolved as the design approach of choice. This chapter describes the in situ approach, and formalises this as a three-phase design process, incorporating exploration (Phase 1), iterative design and evaluation in situ (Phase 2), and integration evaluation (Phase 3). All of these phases emphasise frequent engagement with key stakeholders, which it is argued is central to this process, and ultimately to acceptance outcomes for the technology. The design methodology for SARs in clinical settings is the first novel contribution of this thesis which will lead to the development of a prototype, and will set up all other contributions of the thesis.

Below the project context is described along with, stakeholders and the implementation of these two phases of development.

3.1.1 Project Setting

The proposed SAR system was developed in close partnership with a busy paediatric rehabilitation clinic in a city-based children's hospital. The rehabilitation clinic consists of 25 full-time equivalent clinical staff servicing, on average, 180 inpatients annually, as well as several thousand outpatient sessions. Patients seen at the clinic range from those recovering from physical injury and illness to those being treated for specific chronic disabilities. Inpatients generally undergo intensive rehabilitation programmes requiring multiple sessions of rehabilitation per day. While some sessions are supervised by physiotherapist staff, others may be facilitated by on-ward nursing staff, or the patient's parent. A particularly prominent patient group are those children with CP. In many cases, orthopaedic surgery is required to correct secondary musculoskeletal problems which impact on gait and function. Such patients typically undergo up to three rehabilitation sessions per day, over a 2 to 3 week period [221].

3.1.2 Stakeholders

The following four groups were identified as key stakeholders in the development of the SAR for rehabilitation.

Patients: the primary beneficiaries of the SAR through potentially increased motivation and sustained emotional well-being, faster recovery time and improved rehabilitation outcomes. They are chief determinants of the SAR's interaction design.

Therapists/Healthcare providers: the primary users of the system, with use-cases spanning both in-session use as well as pre-configuration for sessions without their direct supervision. They are determinants of the SAR's therapeutic assistance, correctness (eg., exercise demonstrations), usability, integration and fitness for purpose.

Parents/Guardians: the holders of primary duty of care for patients, who are often present during therapy sessions and tasked with ensuring rehabilitation exercises are performed outside of formal therapy sessions (e.g., on-ward, after-hours). They are thus targeted end-users of the system, and determinants of the system's usability, and fitness for purpose.

Technology Developers: the people who engage with all other stakeholders to determine the SAR system requirements, design and implement interactive behaviours and operate the SAR during development and testing. They gather feedback from other stakeholders, assess the system's technical performance, and the feasibility of identified roles and requirements.

3.1.3 Design and Development

The design and evaluation approach in this thesis has consisted of three phases. The first, an exploratory phase to elicit basic requirements, ran for 10 months between March 2015 and January 2016, some of which occurred prior to the author's commencement of candidature. The candidate, Felip, started in November 2015 by the end of the exploratory phase. The information collected during the exploratory phase was analysed by the candidate in order to understand the needs of the clinical setting. Previous work, as reported in Chapter 2, has not thoroughly explored in the intended place of use a basic set requirements for SARs in paediatric rehabilitation. Thus, the exploratory phase was required in order to understand the needs of the clinical setting.

The second phase, involving the iterative development and in situ evaluation of a first prototype implementation, began in March 2016, until December 2017. Being core to this thesis, the methods associated with Phase 2 are the focus of this chapter, with results presented in Chapter 4 and Chapter 5. Through these design phases, a prototype for formal clinical trials has been targeted.

The third phase of the development and evaluation process examines performance of the SAR prototype, after iterative development in Phase 2, as an integrated therapeutic aid. This phases' emphasis is thus on eliciting further requirements that become evident when fully deployed on-ward, where the SAR is in daily use with the same patient over a period of time. Phase 3 took place in 2018 and at beginning of 2019 in the form of interviews to physiotherapists and case studies, with results presented in Chapter 6 and Chapter 7. All phases of the design and evaluation process are described in more detail below. Figure 3.1 shows the timeline of development.

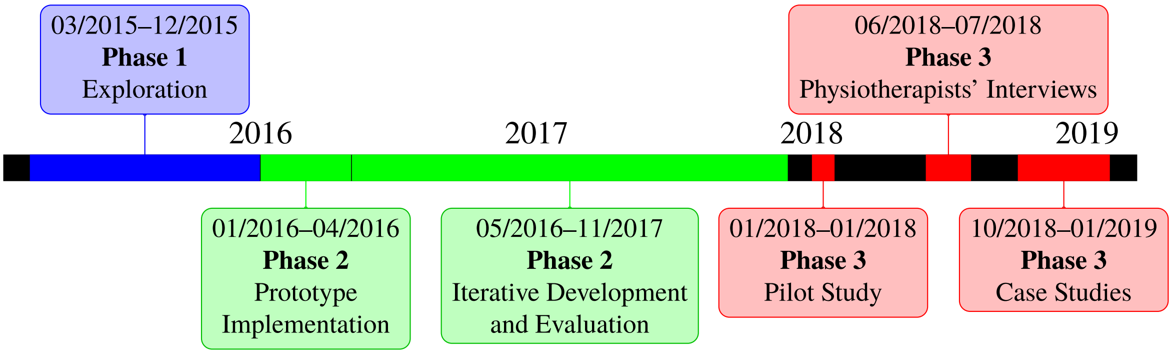


Figure 3.1: Timeline with the deployment phases.

3.1.4 Phase 1: Exploration

The initial phase of the SAR's design, previously described by McCarthy et al. [143], prioritised two key activities: regular and frequent (weekly) stakeholder engagement, and rapid prototyping and mock-ups of proposed roles and capabilities. Both activities were conducted primarily on-site, in the context of the robot's intended deployment.

A regular weekly pattern of visits to the clinic was established in the early weeks of the phase. Each Tuesday morning attending research team members (typically two) setup NAO in a publicly visible and accessible location, close to consultation rooms with high visibility to patients, their families, and therapists. This facilitated regular, albeit brief, discussions with therapists and parents at the beginning. Patient interactions were initially also brief, unstructured and intermittent, typically occurring during their time waiting for a consultation with therapists. The use of Wizard-of-Oz control, where subjects interact with the robot believing it is autonomous but the robot is actually being teleoperated, allowed the robot to meet the immediate needs of particular interactions.

Early engagement suggested how to overcome the technology limits and foster effective engagement with patients. It facilitated development of core exercise demonstrations. Therapists were actively engaged in this process, initially through requests to critique NAO's execution of exercises, and also invited to physically manipulate the robot's limbs to both correct and explore the physical capabilities and limitations of the system (Figure 3.2).

Figure 3.2: Carer manipulating robot's limbs.

In the second half of the phase, therapist engagement evolved into a cycle of iterative development in which a therapist directly programmed specific exercises by positioning the robot into key poses, from which robot joint positions were immediately recorded and time sequenced. New exercises were rapidly developed via this process on-site, with refinements made between clinic visits. During this second half of Phase 1, observations determined specific roles (outlined in Section 3.1.7) based on the robot's capabilities.

Patient engagement also progressed from non-specific patient interactions driven primarily by general interest and the novelty of the robot in the waiting area, to the active inclusion of NAO in therapist-selected patient sessions. Pre-built exercise demonstrations were sequenced in accordance with therapist specifications, and trialled in sessions with technical support. Early scripting of robot behaviours was done using the vendor-supplied graphical development environment, Choreographe [174]. This visual programming environment, while limiting in some technical respects due to its highly abstracted *block-style* programming, allowed different Technical Developers to interchangeably operate NAO without requiring specialised knowledge of underlying system complexities, thereby increasing the pool of developers who could assist in this exploratory phase. This supported the maintaining of regular weekly visits throughout Phase 1, and diversified interactions between developers and all non-technical stakeholders.

3.1.5 Phase 2: Iterative Development and Evaluation

Phase 2, prioritises the in situ iterative development and evaluation of a stand-alone prototype. As such, focus was placed on the realisation of a minimum viable SAR based on the roles determined in Phase 1, and the identified key requirements (Section 3.1.8) in both phases for a robot in rehabilitation [136].

As will be detailed in Section 3.4, regular weekly patient sessions with NAO were scheduled in which Wizard-of-Oz control and engineering support was removed from the robot's operation, thus focusing on the needs of ongoing stand-alone operation in a clinical setting. Phase 2 aims to develop the system to be under the sole operation of therapists, parents and/or other care-givers.

Phase 1 established CP as a well suited initial target for clinical evaluation. Phase 2 thus focused on a system capable of leading sessions for patients with CP undergoing post-operative rehabilitation. Exercise capabilities predominantly target lower-limb strengthening in accordance with the typical prescribed programme of rehabilitation for this patient group.

Patients, therapists and parents not involved in Phase 1 were formally recruited and consented to participate in this phase of the study. Data were gathered via questionnaires with all stakeholders at the completion of each session, along with observation notes recorded during each session. Attending researchers observed from an adjacent room with one-way mirror.

3.1.6 Phase 3: On-ward Integration

Phase 3 evaluates the integration of the SAR prototype when fully integrated into the clinical programme of selected patients, and in daily use. This phase takes the form of focussed case studies, removing all technical support during sessions. The aim is thus to assess the

SAR's integration with existing clinical care, and to elicit any further requirements that emerge when used in this full integrated context. The study protocol of the case studies was determined from the learnings of a pilot study and interviews to physiotherapists who participated during Phase 2. Chapter 6 and Chapter 7 will report further details and results of this phase, and thus further discussion is deferred until then.

3.1.7 Derived Roles From Phase 1

Therapist consultation and observation during Phase 1 determined four specific roles encompassing the base-level capabilities the SAR must provide to serve as an effective therapeutic aid in rehabilitation sessions.

Demonstrator: At the beginning of each exercise set, the SAR performs the exercise in front of the child. The SAR also provides verbal instructions to emphasise important aspects of the exercise.

Motivator: The SAR provides verbal encouragement at the beginning of each session, as well as before and during each prescribed exercise. Enticements such as entertainment through music, dancing and joke telling are also offered upon completion of exercise sets.

Companion: The SAR delivers personalised introductory statements at the beginning of the session to build rapport and establish itself as a joint participant in the session. As the child performs each exercise set, the SAR joins in and delivers empathetic and encouraging statements acknowledging the child's progress.

Coach: The SAR guides the patient through the prescribed session by scheduling and coordinating the execution of the above roles to deliver a complete session of therapy. The system paces the delivery in accordance with the patient and therapist/carer responses.

3.1.8 Derived Requirements

To support the above roles, Phase 1 identified the following system requirements.

Configurability

Therapists and Technology Developers in Phase 1 both identified the need for configurability of the system to realise a stand-alone SAR for rehabilitation. Early feedback from therapists requested a system based on current practise in which session schedules are produced by selecting activities from a list. Configuration thus needs to allow pre-selection of exercises to perform, the number of repetitions, speed of execution, entertainment modules, as well as personalisation of the session with the patient.

Stability

Therapists and Technology Developers jointly determined that exercise demonstrations and general SAR actions must operate with a high degree of certainty in order to minimise session interruption and distraction. In the context of an off-the-shelf general purpose social robot, physical characteristics impacting this are not modifiable, and thus must be carefully managed within the programmed movements of the system.

Adaptability

To ensure therapeutic assistance is aligned with the patient's needs, the SAR should be adaptable to the presenting condition of the patient during care delivery. It was observed in Phase 1 that therapists prescribe exercises before a session, but assess and adjust activities during the session. Therapists noted that an effective SAR for rehabilitation should provide mechanisms for dynamic adjustment of activity settings, including number of repetitions, speed and sequence order. Verbal instructions must adjust accordingly.

Interaction

Observations in Phase 1 indicated a general desire of patients to interact with the robot, and this should be facilitated often. Basic interaction with the SAR should always be supported for therapists/carers and patients throughout the session. Challenges observed with speech recognition during Phase 1 made clear that interaction should be multimodal (eg. verbal, tactile, etc.) to cater for varying patient needs. This will support Adaptability, Responsiveness and maintain patient engagement.

Integration

Previous work (eg., Mutlu and Forlizzi [158]) and Phase 1 observations highlighted the need to ensure setup and use of the SAR was well integrated with existing clinical practise, and the general operating conditions of a busy hospital-based rehabilitation clinic. Therapists and Technology Developers together determined that the SAR must be easily setup by therapists and care-givers, be portable and transportable by a single person, and operable by carers with minimal training requirements.

Responsiveness

Observations by Technology Developers in Phase 1 and early Phase 2 sessions indicated that a lack of responsiveness to unprompted verbal statements from patients may diminish the perceived authenticity of the SAR's role as a companion. Observations also highlighted that the implementation of responses should also incorporate awareness of the patient's mood and progress to support the SAR's motivator role.

Stand-alone

Therapists and Technology Developers jointly agreed that the system should be operable without engineering support, Wizard-of-Oz control, or additional hardware to meet the needs of flexible and un-hindered ongoing use. SAR activities requiring human assistance should also be minimised to ensure carer focus remains primarily on the patient. Therapists also expressed a strong desire to have the SAR present and ready to use at the hospital at all times.

Robustness and Endurance

To meet the requirements of leading patients through rehabilitation sessions, therapists and technology developers determined the system needs to operate continuously and for a minimum of 30 minutes without engineer intervention. To support the stand-alone requirement, unforeseen interruptions such as falls, slippage, or unintended/incorrect user interactions should also be recoverable from, either automatically, or through a clearly understood set of instructions for the therapist and/or care-giver to follow.

Section 3.2 and Section 3.3 outline the technical implementation and key design decisions to maximise the realisation of these baseline roles and requirements derived from Phase 1.

3.2 SAR Prototype Implementation

A SAR prototype was implemented from the learning of the exploratory Phase 1 and initial testing in the iterative development phase (Phase 2). This section outlines the technical implementation of the key requirements outlined in the previous section, and the different activity scenarios of the software prototype.

3.2.1 Software Modules

The prototype software for the NAO robot platform utilises the Robot Operating System (ROS), an open-source robotics framework. ROS was chosen on the basis of its extensibility and strong support for simplified communication between different tools, and devices in a robotic system [179].

ROS Kinetic Kame is the ROS version adopted for the prototype since it became available in May 2016. ROS is written in C++, Python, and Lisp; ROS Kinetic Kame minimum requirements are C++11 (GCC 4.9 compiler), Python 2.7, Lisp SBCL 1.2.4, CMake 3.0.2, and Boost library 1.55. The operating system of the NAO robot, NAO version 4 and 5, is NAOqi 2.1.4.13.

The `nao_robot` ROS stack is required to run the software developed for the SAR prototype, in particular `nao_bringup` and `nao_apps` need to be installed. The latest version of those packages from the ros-naoqi github repository is manually compiled and installed using catkin build system.

Figure 3.3 shows some of the basic modules of the NAO robot for ROS and the three modules implemented in our system. We briefly describe each below.

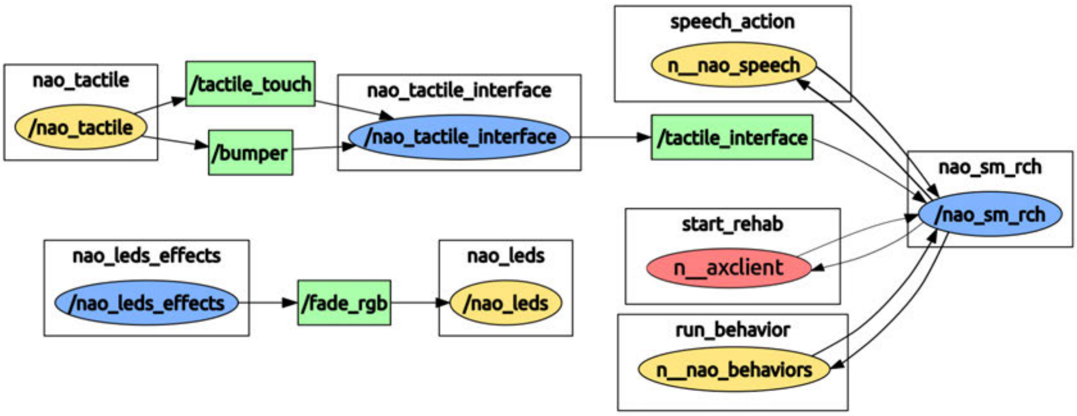


Figure 3.3: ROS modules simplified for the SAR. In blue: ROS nodes implemented for the prototype. In yellow: ROS nodes that connect ROS with NAO's server. In green: the ROS communication topics. In red: the graphical actionlib client to start the session from a remote computer.

nao_sm_rch

`nao_sm_rch` is the main module of the system, incorporating all rehabilitation activity scenarios, including speech, lower body exercises, games, and dances. This is implemented as a finite state machine initiating specific scenarios via connections to other nodes of the system.

Services such as `run_behavior` or `speech_action` are called from this node in order to execute a predefined movement, or to make the robot speak. To assist data collection, the module also maintains a logfile tracking all the exercises executed, timing data, and user-inputs.

nao_tactile_interface

`nao_tactile_interface` is implemented as a ROS service to capture and detect inputs to the system such as from touch sensors and bumpers using the `nao_tactile` library. This interface detects single, double and long button clicks, allowing numerous different responses to be invoked.

nao_leds_effects

`nao_leds_effects` provides visual prompts and conveys the system state. This service has been configured using the ROS NAO library `nao_leds` with 5 different LED effects that are activated to cue the need for the robot's head to be tapped in order to continue the session, or to indicate a session configuration file is being loaded.

Figure 3.3 shows other ROS libraries from the `nao_robot` ROS stack being used such as `nao_leds`, `nao_tactile`, `run_behavior` and `speech_action`. The robot is configured and started using the `start_rehab` action library.

All the software runs from a laptop (server), the laptop establishes a Wi-Fi hotspot so the NAO robot can connect to the server through a wireless connection. Once the connection is established, two ROS launch scripts need to be executed: `nao_bringup` and `nao_sm_rch` which also launches all its dependencies.

3.2.2 Activity Scenarios

The prototype for Phase 2 trials incorporated 16 different activity scenarios to support the roles outlined in Section 3.1.7. Activity scenarios were all the rehabilitation exercises (N=13), plus an introductory speech delivery, a toy relay game, and entertainment routines. In the introductory speech the robot introduces itself to the patient, or greets a patient it has previously interacted with. In addition to statements explaining what is planned for the session, the scenario includes jokes and pre-programmed dialogue to foster rapport building. Several introductory speeches can be selected from to reduce repetition over multiple sessions. Such option selections were initially facilitated via a pre loaded text-based configuration file.

Sessions consist of multiple exercises, each involving several sets and repetitions. Adjustments to exercise speed, if requested during the session, can be changed by the carer using the *Tactile Interface*, explained in more detail in Section 3.3.7. For each exercise, the SAR presents a demonstration while explaining key features of the exercise. The patient is then invited to join the SAR in completing a set together. During exercise execution the SAR provides encouragement and therapist-selected reminders about key aspects of each exercise (Section 3.3.5). At the completion of each set, the SAR requests the patient (or carer) tap its head to continue. The SAR asks for help when human assistance is required to setup a particular activity (Section 3.3.8).

The Phase 2 prototype was equipped with 13 different rehabilitation exercises: a sit-to-stand exercise (Figure 3.4) and 12 executable from a lying down position (Figure 3.6). These exercises represent core lower-body exercises typically prescribed in the rehabilitation programme of patients with CP. Exercises have been programmed with the help of physiotherapists, through manual positioning of the unstiffened robot to capture key postures and the temporal sequence of transitions for each exercise [143]. This is supported using the vendor-supplied development environment, Choreographe [174].

Figure 3.5 depicts an activity scenario in which the robot guides patients through a so called *toy-relay* game. In this scenario, the robot asks the patient to fetch named toys on the other side of the room. The activity encourages patients to walk while the robot provides instructions and motivational statements.

A final supported activity scenario provides a farewell, rewarding the patient's efforts at the end of the session with a dance. Dance options include one programmed entirely by a physiotherapist on the research team.

3.3 Design Decisions

The Phase 2 prototype provides a baseline system enabling NAO to facilitate the completion of prescribed rehabilitation sessions. Design requirements outlined in Section 3.1.8 were carefully considered in the context of ensuring a reliable system for ongoing iterative development. This section discusses specific design choices, compromises and considerations that were made to meet this objective.

3.3.1 Activity Configuration Interface

Phase 1 required programme code to be explicitly written for each session to meet the needs of each individual patient. However, to fulfil both *Configurability* and *Stand-alone* requirements, all activity scenarios in the Phase 2 prototype (outlined in Section 3.2.2)

Figure 3.4: **Sit-to-Stand** exercise: The patient taps the robot's head to initiate the robot's stand up sit down actions while the child follows. [Guardian consent provided]

Figure 3.5: NAO leads a patient with cerebral palsy through the **Toy Relay** game during a therapy session. [Guardian consent provided]

(a) Bridge **(b)** Hip Abduction Laying **(c)** Hip Abduction on Side

(d) Single Bridge **(e)** Hip Extension Easy **(f)** Hip Extension Hard

(g) Hip Knee Flexion Sliding **(h)** Hip Knee Flexion Lifting **(i)** Knee Extension on Side

(j) Leg Raises **(k)** Quads over Roll **(l)** Static Quads

Figure 3.6: Rehabilitation exercises executable from a lying down position. (a) Bridge: Strengthening exercise for the hip extension muscles; **(b) Hip Abduction Laying:** Strengthening exercise for hip abduction muscles; **(c) Hip Abduction on Side:** Progression of hip abduction laying; **(d) Single Bridge:** Progression of double leg bridge; **(e) Hip Extension Easy:** Strengthening exercise for the hip extension muscles. This is easier than bridges and can be done with children who are not allowed to take weight through the legs; **(f) Hip Extension Hard:** Progression of Hip Extension Easy. Keeping the knee straight while extending the hip makes this exercise harder; **(g) Hip Knee Flexion Sliding:** Strengthening exercise for the hip flexors and can also be used to encourage increased range of movement at the hip and knee. The weight of the leg is supported by the bed; **(h) Hip Knee Flexion Lifting:** Strengthening exercise for the hip flexors and improving range of movement at the hip and knee; **(i) Knee Extension on Side:** In this exercise gravity is eliminated, meaning it is an easier exercise for strengthening the muscles that extend the knee; **(j) Leg Raises:** Strengthening exercise hip flexors and quadriceps; **(k) Quads over Roll:** Strengthening exercise for the hip extensor muscles; **(l) Static Quads:** This exercise is used to start practising engaging the muscles that extend the knee. It is easier than quads over roll.

were selectable and configurable via a text-based interface, avoiding any code modifications between sessions. This implementation allows a session to be configured by selecting and sequencing exercises in the system, together with the number of sets, repetitions and execution speed. Other parameters entered to personalise the session are the patient and the carer's name. Configuration of the SAR during Phase 2 was done via a text file edited by a Technology Developer on behalf of the therapist. During the course of Phase 2, a tablet-interface was developed in parallel to replace this system, and was deployed in later sessions of Phase 2. This is discussed further in Chapter 4.

3.3.2 Rehabilitation Exercises

All rehabilitation exercises and activities described in Section 3.2.2 are standard exercises in existing rehabilitation programmes (*Integration* requirement). However, changes to the initial design of some exercises were required to accommodate *Stability*, *Robustness* and *Endurance* requirements. For example, the Sit-to-Stand exercise was originally designed to work with a seat, requiring pre-positioning before exercise execution. However, due to an observed high risk of failure in Phase 1 (eg., movement of the seat or incorrect positioning), the activity was redesigned in consultation with therapists to incorporate a crouching action instead. This was more reliable and simpler to initiate.

Walking exercise demonstrations were trialled in Phase 1, but not included in the Phase 2 prototype. In line with Malik et al. [134], therapists deemed the crouching gait of the NAO robot as not appropriate for demonstration to patients. Furthermore, Phase 1 highlighted issues with both the speed and stability of NAO's walk. For example, the toy-relay activity scenario was designed to motivate walking in the patient by having the robot issue instructions, and through face tracking and motivational utterances, provide patients a sense of being monitored and encouraged during the activity (Figure 3.5).

3.3.3 Activity Execution Order

It was observed during rehabilitation sessions in Phase 1 that therapists often wanted to modify the schedule of exercises, to better adapt to the patient's mood and energy levels. This was easily facilitated in Phase 1 with Technology Developers in place, but required careful consideration for Phase 2's focus on a stand-alone system. Providing therapists with the ability to schedule the execution order of rehabilitation activities was thus deemed central to the *Flexibility* requirement but needed careful balancing with *Stability* and *Endurance* requirements of the system. For example, while some therapists expressed a desire for on-line reordering of activities during sessions, this was not incorporated into the initial Phase 2 prototype due to increased risk of failure during transitions between some exercise poses. This decision was supported by observations of care delivery in Phase 1, which revealed a general tendency for therapists to maintain the basic order of exercises, and in particular, to group exercises based on the required posture or stage of the session (e.g., lying down versus standing-up, muscle strengthening versus relaxing).

3.3.4 Exercise Speed

The speed of exercise execution was noted as something that needed to be changeable during sessions. Phase 1 made clear that not all patients perform exercises at the same speed, and during intensive rehabilitation, are likely to progress to more capable levels. Physiotherapists request children perform exercises at different speeds based on their clinical observations of exercise performance. This may include performing some exercises faster, or slower, or holding a position for longer. Therefore, all the exercises were programmed for three different speeds, allowing therapists the ability to select a speed during pre-configuration, and during the execution of an exercise set to support the *Adaptability* requirement (more details explained in Subsection 3.3.7).

Static Quads is the fastest exercise in which each repetition in the fast speed setting takes 2 seconds, dropping to 5 seconds in the slow speed setting. Hip Abduction is the slowest exercise, in which each repetition takes 7 seconds on the fast speed setting, increasing to 15 seconds when set to slow speed. Exercise speeds were validated during pre-Phase 2 testing based on initial observations of the robot performing the exercises and then clinical observation of a child performing exercises with the robot. Physiotherapists provided feedback to Technology Developers to make speed adjustments based on this.

3.3.5 Human-Robot Interaction

Robot Gestures and Speech

Observations during Phase 1 and pre-Phase 2 testing prototype highlighted a need for speech at frequent and intermittent points to avoid long periods of silence. In Phase 1 this was easily accounted for through Wizard-of-Oz operations, but the *Stand-Alone* requirement forced the Phase 2 prototype to be equipped with an extensive scripted list of utterances, selected randomly within the software, for specific activity scenarios. Therapists suggested the inclusion of motivational statements, as well as reminders of important aspects of the movement to maximise therapeutic benefit. Motivational statements such as *"Keep it Going!"*, or *"Every exercise we do gets us closer to my awesome dance moves!"* were randomly selected, and interleaved with exercise-specific reminders such as *"Can* *you lift your bottom any higher?"*, or, *"Keep your toes pointing up!"*. Constant feedback was also provided during exercise execution by counting each repetition aloud.

Due to robustness and reliability considerations in the Phase 2 prototype, no patient progress monitoring was incorporated into the SARs feedback to patients. Thus, statements were designed to be relevant to the specific exercise, but not specific to the particular patient's current actions or progress. While therapist feedback made clear a desire for patient-monitoring to inform the delivery of statements, this was not possible to implement to the level of accuracy and robustness required within the time frame of this study. It was also not regarded as a prerequisite to clinical deployment in Phase 2.

Along with speech, animated gestures and actions were incorporated into the SAR. In a study with 16 males and 16 females from a university campus, Chidambaram et al. [32] studied how appropriately designed vocal and non-verbal cues can increase compliance in people when instructed by a robot. Accordingly, related body cues were incorporated matching the robot intonation and speech to enhance compliance and the overall authenticity of interactions with patients.

Speech Recognition

The challenges of speech recognition with social robots such as NAO, and for voice recognition with children more generally, are well documented in the Human-Robot Interaction literature [106]. Pelikan and Broth [170], for example, note issues associated with the required turn-taking between robot and human when delivering speech, which users often find difficult to adapt to. Challenges due to insufficient loudness of voiced responses, or unexpected statements provided by human users, all pose significant challenges for SARs seeking to foster natural and authentic interactions with users.

Phase 1 confirmed all of these issues as significant challenges, but also highlighted issues more specific to the clinical context. For example, errors in speech recognition would cause NAO to provide inappropriate responses due to misclassification of responses to questions such as *"How are you going?"*. Negative patient responses were sometimes classified as positive (and vice versa), potentially impeding the SAR's primary role as a motivator and companion. This was exacerbated by the relatively young age of children, and in some cases, speech impediments relating to their disability. A lack of response to a patient's answer would also result in long periods of silence, often requiring a supervising adult to intervene and repeat the command.

Such challenges, however, were countered by Phase 1 observations that children reacted positively when the robot did respond appropriately. The incorporation of limited speech recognition was thus deemed important to realise *Interaction* and *Responsiveness* requirements. To preserve *Stand-alone* and *Integration* requirements of the system, bidirectional communication was governed by specific structural choices to constrain possible responses, and to ensure *robustness* to misclassified utterances. These choices included:

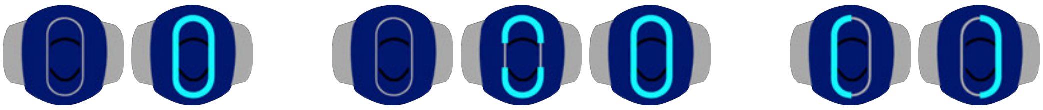
- Prompting users only for simple, specific one-word verbal responses such as: *"When you're ready to start, just say 'go!' "*, and/or asking scripted questions with a constrained set of possible one-word responses (eg., Yes/No).
- Providing non-verbal tactile-based interaction alternatives. For example: *"Sorry, I didn't hear you! You can also tap my head to continue"*.
- Providing speech recognition with an array of possible responses from which to base speech classification. For example: *"Yes", "Yeah", "Sure", "Okay", "Yep"*.
- Capping the waiting period for a patient response at two seconds to ensure no undue pressure was placed on the patient to provide a response. A two second listening time was chosen from empirical observations in Phase 1. A lack of response would simply be followed by a generally relevant statement before continuing execution of the scenario.

A limited number of more open interactions were also included to allow patients the opportunity to engage more freely and express feeling and emotion (eg., *"How are you going?"*). Such interactions were included, in part, to allow supervising care-givers (and Technology Developers) a chance to gauge the patient's emotional state during the session. SAR responses to patient answers were designed to be generally relevant rather than response-specific. For example, a patient's response, either negative or positive, might be followed by the generic statement: *"I am having a great time doing these exercises together with you"*.

3.3.6 Visual Cues

To support *Interaction* and *Stand-alone* requirements, NAO provides multiple LED outputs to prompt user input and convey the system state. LEDs around the three head-buttons of the NAO are used extensively to cue required button presses to confirm progression to the next activity. LEDs blink at 2 Hz, cueing the need for the head to be tapped either between exercise sets, or when changing activity scenarios. Phase 1 indicated visual cueing greatly improved the ability and confidence of people to perform the task. Full blinking of head LEDs is used to cue confirmation of progression to the next activity (Figure 3.7a). Other patterns of LED flashing convey the system is setting up (Figure 3.7c), or in a paused state (Figure 3.7b).

Additional LED cueing on either side of NAO's head conveys the expectation of a verbal input - most commonly as an alternative to head tapping for confirming progression to the next activity.



(a) (b) (c)

Figure 3.7: LEDs effects (grey and thin line when LEDs are off, cyan or thick line when LEDs are on). **(a) Prompting a patient/carer head-tap**. **(b) Indicating system is paused**. **(c) Indicating a system setup in progress**.

3.3.7 Tactile Interface

Use of the NAO's head-based tactile sensors provides carers and patients an alternative to speech for SAR interaction. In therapy sessions, patients were able to use the tactile interface when prompted to continue to the next activity, or to start another set of repetitions. To ensure simplicity for patients, this was achieved via a single tap of any of the three buttons (Figure 3.8a).

To support online *Adaptability* and *Configurability* requirements, head taps were also used to provide carers the ability to adjust activity settings. Most prevalent in Phase 1 observations were scenarios in which patient performance required adjustment of exercise speed, or pausing of the session to accommodate unpredictable actions.

Speed adjustments were made using a sustained press of the NAO's middle head touch sensor, followed by a double tap of the front sensor to slow down the exercise, or to the rear sensor to speed it up (Figure 3.8b). To pause the robot, the rear and the front button were long-pressed at the same time (Figure 3.8c). Robot adjustments were deliberately made less simple than head taps to prevent adjustments by mistake (*Robustness* requirement).

3.3.8 Human-assisted Activities

While NAO offers the potential for a high degree of autonomy, Phase 1 observations highlighted limitations in the context of its ongoing therapeutic use. Physical constraints as well as other system uncertainties limit the ability of the robot to perform certain exercises, attain certain postures, or position itself with respect to supportive auxiliary aids. Even where autonomy may be possible, motor wear-and-tear, uncertainty of success and time costs associated with completing some actions autonomously motivated the use of human assistance in certain instances to meet *Robustness*, and *Stability* requirements.

(a) Continue/Go!

(b) Changing Speed.

(c) Pausing.

Figure 3.8: Tactile interface. **(a) Continue/Go!** a single tap on any of the three tactile buttons (middle, front, or rear) when requested by the SAR to continue. **(b) Changing Speed:** One finger middle button long press while second finger double tapping the front bottom to go faster, or double tapping the rear button to go slower. **(c) Pausing the robot:** Long press to front and rear buttons at the same time.

The inclusion of robot capabilities needing human assistance, while unavoidable, required careful consideration. To meet *Integration* and *Stand-alone* operation requirements, the inclusion of activity scenarios requiring carer assistance needed to be complimentary to existing carer tasks - in particular, preserving the carer's focus on the needs of the patients. In consultation with therapists, the following human-assisted capabilities were implemented in the Phase 2 prototype:

Positioning: Activity scenarios could be done in a range of different places and different positions: On the floor, on a table, laying down, standing up, etc. While NAO can stand-up or lie down by itself, manual re-positioning, in which the therapist lifts and places the robot close to the patient, was preferred due to being quicker, less error-prone, and reduced wear-and-tear (Figure 3.9a) than having the robot position itself.

Placing auxiliary aid: *Quads over Roll* and *Static Quads* are the two exercises where, as with the patient, a small rolled towel is placed under the leg of the robot (Figure 3.9b). The robot explicitly asks for assistance:

"For Quads over Roll we will need to roll two towels. One big for you, and a little one for me! We have to put the towel under our left knee".

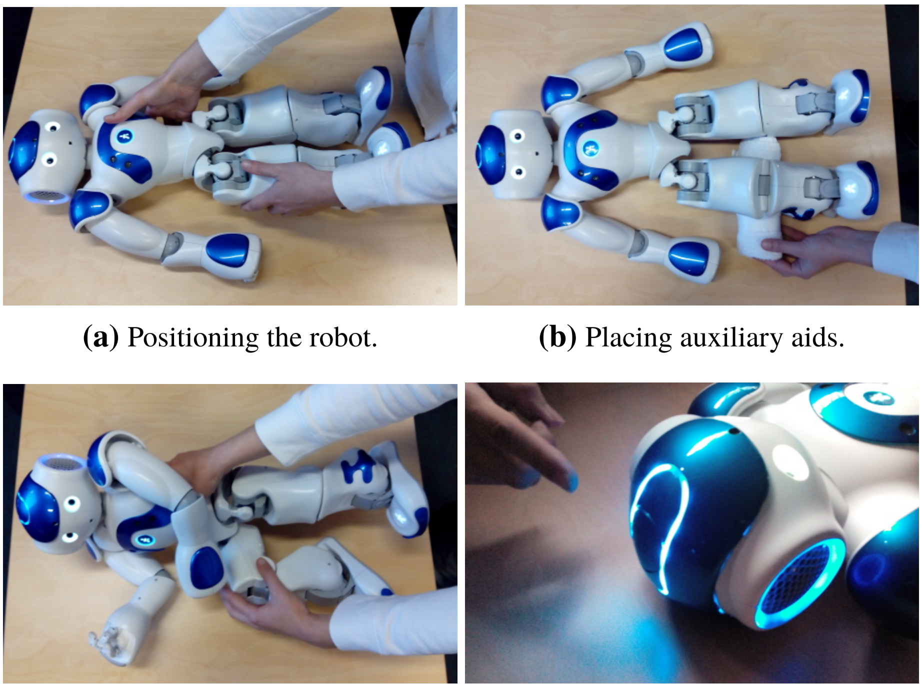
Posture: *Hip Abduction on Side*, *Hip Extensions*, and *Knee Extension on Side* are exercises where the robot needs to be rolled onto its side (Figure 3.9c). Like with auxiliary aids, the robot asks explicitly for this kind of assistance:

"For this exercise, I will need your help! I will need you to roll me onto my right side. Can you do that for me?"

Keeping pace: Between exercises the SAR lets the patient rest. A head-tap (Figure 3.9d) is used to indicate progression to the next activity. Head-taps are also used to confirm progress during instructional activities such as *Sit-to-Stand* or *Toy Relay*.

"Say Go! Or tap my head when you are ready to start the next set"

In Section 4.1.4 we present a preliminary analysis of time costs associated with human-assisted activities. Post study interviews in Chapter 6 will further examine the impact of the semi-autonomous robot in therapy delivery.



(a) Positioning the robot. **(b)** Placing auxiliary aids.

(c) Posture. **(d)** Helping to keep pace.

Figure 3.9: Examples of Human-assisted activities.

3.4 Phase 2 Methods

The Phase 2 prototype, incorporating all the features and design choices described in the previous sections, was ready for formal testing early May 2016. Before formal data collection commenced, the robot was deployed as part of the standard clinical care delivered to selected patients at the Royal Children's Hospital. This pre-Phase 2 testing was performed to test basic system functionalities, and to inform the protocol design. Formal recruitment of participants, data collection, and evaluation of the prototype commenced in August 2016 when ethical clearance was obtained from both the hospital and university ethical approval process. There were 41 rehabilitation sessions run in Phase 2, delivering in total 19 hours and 7 minutes of physiotherapy.

The method described here forms the basis of results to be reported in Chapter 4 and Chapter 5. Chapter 4 will examine the performance and iterative development of SAR over the course of these Phase 2 trials. Chapter 5 analyses user acceptance across the three user groups: patients, parents and therapists. Discussion of the data collection surveys for this is deferred until Chapter 5.

3.4.1 Recruitment

Twenty patients (11 male and 9 female) between 5 and 16 years old were recruited from August 2016 to November 2017. Patients were recruited based on: having a rehabilitation programme consistent with the robot's exercises, and their physiotherapist's clinical judgement. Patients were invited to participate between 1 and 3 rehabilitation sessions, depending on their availability and willingness.

The treating physiotherapist of the patient was recruited to deliver the rehabilitation session operating the robot. Parents were also recruited to observe the rehabilitation session. After completing a session, patients and parents were given the option to participate in an other session, where the parent was invited to operate the robot based on physiotherapists clinical judgement. This is explained in more detail in Chapter 5.

3.4.2 Testing Setup

Phase 2 clinical sessions with the robot were conducted in a consultation room at the rehabilitation clinic of the Royal Children's Hospital, Melbourne, Australia. Observing investigators were located in an adjacent observation room with one-way mirror (see Figure 3.10). The participating patient, therapist and the SAR were in the Participants' room. Parents observed the session from either of the two rooms depending on their preference. All participants were informed that sessions were being observed by research team members. Pre-configuration of the system was performed by a research team member. Configuration options were communicated to the research team member by the treating therapist prior to each session.

Before starting the session, the robot was placed in a crouched position on a table-top next to the bed and the attending therapist received a 5 minute informal introduction to the system by the physiotherapist researcher. In this introduction it was explained that the robot will work autonomously, will be able to recover from some failures, however may ask for help for particular positioning requirements, or request head-taps to confirm session progression.

The session started with the robot greeting the patient and introducing itself. NAO then commenced the patient's pre-configured exercise programme as described in Section 3.2.2.

NAO's software ran off a laptop with wireless connection to the robot. During each session, an attending research engineer monitored the software in the adjacent observation room, and interacted with the system only if necessary (ie., a system failure requiring a reset of the system). All operational requirements were thus handled by attending caregivers and the patient. The protocol allowed engineer intervention to occur only when a
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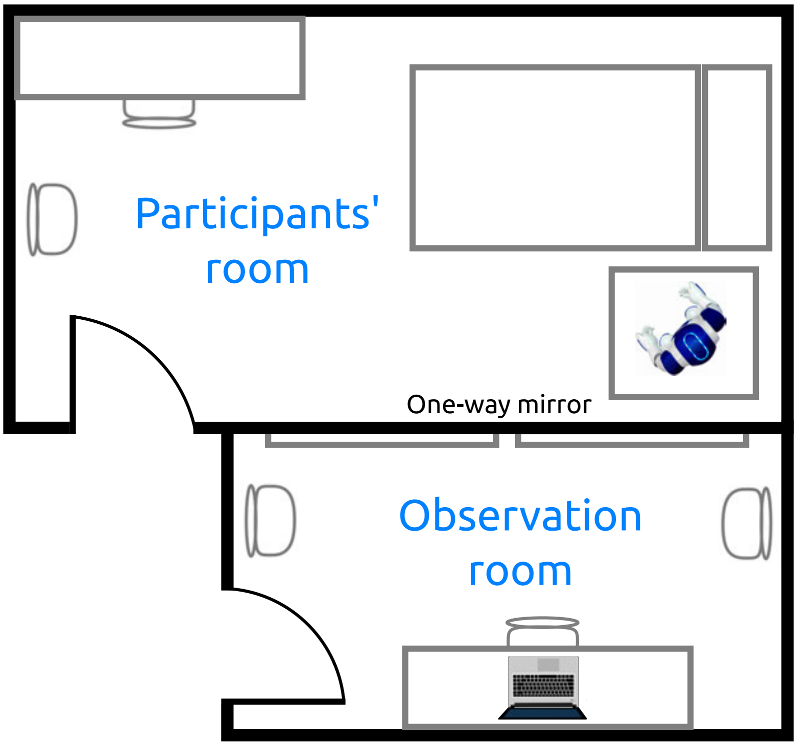


Figure 3.10: Study setting floor plan.

3.4.3 Data

During every session observation notes were recorded by the attending researcher (author of this thesis). Software logs also recorded information about the system performance and interactions, including delivered speech, time, number of exercises (sets and repetitions), participants' inputs via button taps, and speech recognition confidence levels for voice commands.

System disruptions, errors, technical interventions, participants' reactions to those issues, and participants' interaction with the robot were the main focus of the researcher's observation notes.

A key focus of Phase 2 testing is the evaluation of the SAR delivering therapy in terms of perceived utility, ease of use, and participants' trust of the robot as a therapeutic device. To this end, survey response data were collected using adapted versions of the robot Acceptance Questionnaire originally proposed by Heerink et al. [85], the Godspeed Questionnaire [8], and open ended questions. This is explained in more detail in Chapter 5.

3.4.4 Phase 2 Data Analysis

Phase 2 data analysis was performed at the completion of Phase 2 data collection. The details of this analysis, addressing both the system's performance throughout Phase 2, and participant perceptions and acceptance, are reported in Chapter 4 and Chapter 5 respectively. Below the preliminary findings are reported.

3.5 Summary

This chapter have presented the in situ design process for the development of a SAR for paediatric rehabilitation. The three-phase process of exploration, iterative development and integration evaluation, embedded in the busy rehabilitation clinic of Melbourne's Royal Children's Hospital, forms the basis of this thesis, examining how a general purpose off-the-shelf social robot, NAO, can be adapted and deployed as a stand-alone therapeutic aid leading rehabilitation sessions with patients.

The chapter lists the set of roles and requirements for a SAR in paediatric rehabilitation, derived from an initial exploratory phase in order to develop the first prototype. The chapter also explains the design considerations to satisfy the roles and requirements.

A deliberately conservative prototype has been developed for Phase 2 testing. While limited in capabilities, NAO's fast-tracked deployment as a robust minimalist system aims to provide crucial patient engagement experience, and insights into what is required for ongoing clinical deployment, and in particular, a formal clinical evaluation of its therapeutic benefits.

The next chapter (Chapter 4) describes how this iterative development and in situ testing has informed the design improvements of the robot during the Phase 2 study. The chapter also evaluates the system performance of the robot in terms of robustness and number of exercises completed during the Phase 2 study. Chapter 5 will formally evaluate the participants acceptance of the robot prototype delivering rehabilitation during the same period during the Phase 2 study.

Chapter 4

In situ Development and Performance Evaluation

The previous chapter introduced the in situ design process for a Socially Assistive Robot (SAR) in paediatric rehabilitation. The design process consisted of an exploratory phase (Phase 1) in which a set of roles for a social robot to deliver rehabilitation were derived. The roles of the robot and the identified key requirements from both phases (Phase 1 and Phase 2) guided the design of a first robot prototype.

Phase 2 of the design process combines iterative development of the prototype in situ, with ongoing acceptance and usability testing. I address these Phase 2 components in two separate chapters, each addressing different aspects of the SAR's evaluation. In this chapter, I report on the operational performance of the robot. That is, system disruptions, technical interventions, system design implications, as well as participants' suggestions for iterative improvements of the prototype. Chapter 5 will provide a formal evaluation of the SAR Phase 2 prototype in terms of participants' perceptions and level of acceptance of the robot prototype as a therapeutic aid for paediatric rehabilitation. The combined results of these chapters seek to provide the most comprehensive understanding to date of the implications of deploying SARs in rehabilitation settings, highlighting the impact of specific design choices on user perceptions of the system, and on its reliability and overall technical performance.

This chapter is structured as follows. The iterative improvements of the robot, and system design implications, are explained in Section 4.1. Section 4.2 provides an overview of the robot performance in the rehabilitation sessions, and explains how issues that have arisen have been addressed to develop a SAR for ongoing clinical deployment. Finally, Section 4.3 summarises the chapter.

4.1 Iterative Development

In line with the in situ design methodology outlined in Chapter 3, Phase 2 involved iterative improvements of the system based on observations and stakeholder feedback. The first prototype (V0.0.0) was developed by the author of this thesis from the learnings of Phase 1. Issues or areas for improvement of the system during the rehabilitation sessions were noted by researchers or therapists, in order to update the prototype with new functionalities or bug fixes. After the system updates, the prototype was evaluated again in the next scheduled rehabilitation session.

Table 4.1 provides a summary of the improvements made in each version of the prototype in chronological order. Minor version changes are for minor modifications of the system such as bug fixes or minor speech alterations (sentences). New functionalities programmed into the robot are indicated with a medium version change. Version 1.0.0 of the prototype included major system improvements when preparing the SAR for Phase 3.

Table 4.1: Prototype versions.

Version	Date	Improvements
V0.0.0	9 MAY 2016	First version of the Socially Assistive Robot prototype.
V0.1.0	11 MAY 2016	Robot will ask to be tapped before standing-up and laying-down. Statements delivered every 2 repetitions during laying down exercises. Change speech to let the patient rest between exercises: “Once you are ready, touch my head to start”. Providing an alternative to voice commands to continue the session: “Say GO! or tap my head”.
V0.1.1	30 MAY 2016	Modification of motivational speech that confused participants. Bug fix: Exercise did not execute due to a variable error.
V0.2.0	09 JUN. 2016	Introductory speech for 2nd session Incorporated. Toy Relay incorporated.
V0.3.0	08 JUL. 2016	Introductory speech for 3rd session Incorporated. Sit-to-Stand exercise Incorporated. Logfile Incorporated.
V0.3.1	26 JUL. 2016	Slowing down intro speech 2nd session for better understanding.
V0.4.0	28 JUL. 2016	Sit-to-Stand exercise by crouching, not using a chair.
V0.5.0	5 AUG. 2016	Toy Relay: Delivering statements every 30 seconds while waiting the patient to bring the toy.
V0.6.0	13 AUG. 2016	Statements delivered every repetition during laying down exercises. Toy Relay: Describe and repeat the colour of the animal toy.
V0.7.0	27 AUG. 2016	Farewell: After dance routine, robot says goodbye and crouches. Statements delivered every repetition during Sit-to-Stand exercise. Toy Relay: Minor fix for speech.

V0.7.1	17 OCT. 2016	Fixing Minor bug with speech recognition. Adding more speech for Leg Raise exercise.
V0.7.2	18 OCT. 2016	Hip Knee Flexion Easy/Hard change name to: Hip Knee Flexion Sliding/Lifting.
V0.7.3	20 NOV. 2016	Bug fix: Generated from a modification of the ROS dependencies
V0.8.0	17 DEC. 2016	When exercising, repetition number delivered before doing repetition. When speech recognition fails, the robot provides alternatives. New dance routine Frozen, coded by a physiotherapist. Minor fix in Logfile
V0.9.0	22 DEC. 2016	Tactile interface: allowing to change the speed of an exercise on execution.
V0.9.1	28 JAN. 2017	Fix typo in robot's speech (motivational phrase)
V0.9.2	19 APR. 2017	Fix typo in robot's speech (exercise demonstration)
V0.10.0	2 MAY 2017	New dance routine PPAP, coded by a medical student
V0.11.0	22 MAY 2017	Toy Relay: The robot mentions the number of toys to collect before starting the exercise. Logfile: Capturing SONAR data during the Toy Relay exercise.
V0.11.1	8 JUN. 2017	Adding more speech to Sit-to-Stand exercise
V0.12.0	12 JUL. 2017	All exercises from a lay-down position: adding option for alternating or no alternating legs when doing more than 1 set of an exercise.
V0.13.0	9 SEP. 2017	Reducing complexity to change the speed of an exercise on execution using the tactile interface. The robot will ask for assistance if Sit down, Stand up and Crouch positions fail.
V0.14.0	2 NOV. 2017	Tablet Interface to configure sessions integrated into the system. (Developed by Melbourne University students)
V1.0.0	6 JAN. 2018	7 Different Introductory speeches. Shortening the 3 previous ones. Demonstrations added: Hip Extension Easy/Hard, Sit-to-Stand. Adding different motivational statements for all exercises. Adding specific speech for sitting exercises. Fixing robot postures when changing leg to exercise.
V1.0.1	28 APR. 2018	Important bug fix generated from ROS dependencies.

In this section I explain the main iterative improvements during Phase 2, and I discuss how researchers' observations and participants' experience guided the prototype's iterations during Phase 2.

4.1.1 Speech Delivery

The robot's speech has been carefully adapted to the participants' suggestions and needs during the whole Phase 2. If a robot cannot communicate properly, does not provide clear information, and lacks of sufficient social skills, participants will not accept the robot due to not being useful, easy to use, and enjoyable [41].

No specific feedback about the animated speech, non-verbal cues, was provided by participants during the Phase 2 study, however, general observations of patient reactions suggested the animated speech enhanced the SAR's authenticity with patients.

In the first version of the prototype (V0.0.0), physiotherapists noted that the speech of the robot gave the impression it was not providing the patient enough time to rest between exercises. For example, the robot speech between exercises was: *"[Patient name] Touch my head when you are ready to start [Exercise name]"*. Participants exhibited a sense of urgency to meet the requirements of the robot. Based on the suggestions of an attending therapist, this statement was altered so as to be perceived as less urgent: *"[Patient name], once you are ready, touch my head to start [Exercise name]"*.

The robot was originally designed to deliver motivational statements or exercise reminders randomly every 4 repetitions (V0.0.0). This generated long periods of silence during the exercises, and so based on physiotherapist feedback, was modified to deliver statements every 2 repetitions (V0.1.0). However, statements every two repetitions was still generating long periods of silence, so finally motivational statements or exercise reminders were set to be delivered every exercise repetition from a laying down position (V0.6.0), and for the sit-to-stand exercise (V0.7.0).

Increasing the frequency of statements delivered by the robot, however, also increased the perception of the robot as being repetitive. Studies suggested that perceived repetitiveness can impact negatively in maintaining long-term human-computer relationships [13], or in human-robot interactions for health care [52]. To address this, more variety of utterances with shorter sentences were included for the sit-to-stand exercise (V0.11.1) and for the exercises executed from a laying down position (V1.0.0).

Some physiotherapists, parents and patients were observed being confused with the way the robot verbally counted exercise repetitions. The robot counted aloud the number of the repetitions completed, however, it was suggested by the research team's physiotherapist that the robot should count before doing the repetition (V0.8.0). This change appeared to confuse other participants due to the robot counting before the repetition. It is difficult to conclude which is the optimal way to count aloud repetitions when doing exercises.

The speech of the Toy Relay activity was also altered in different iterations. It was observed that patients can take variable lengths of time to collect the toys and bring them back to the robot. This could cause long periods of silence which was observed to possibly impede the robot's motivational objectives. Therefore, the robot was programmed to deliver different statements or questions every 30 seconds (V0.5.0), for example: *"My favourite animal is the turtle. What's your favourite animal?"*; or *"Careful, the crocodile is getting snappy!"*. While this avoided long periods of silence, it also increased the perception of the robot being repetitive. Furthermore, it was observed in 2 sessions patients sometimes got confused when the robot mentioned specific animals. For example, in one session a patient holding a toy penguin they were asked to collect, approached the robot during the Toy Relay, and the robot commented: *"Careful, the crocodile is getting snappy!"*, causing the patient to bring another toy animal.

Also observed during the Toy Relay activity, a few participants did not understand clearly which animal was being asked for by the robot, either because they were distracted, or because they did not understand the robot. The robot was not equipped to respond to participants' questions, or repeat statements if not understood. As such, it was generally evident that programmed utterances had to be made as clear and as descriptive as possible to reduce the occurrences of such misunderstandings, which also impacted the session flow. In the context of the Toy Relay activity, the speech was modified to include a description of the animal, and the animal pronounced more than once. For instance, instead of delivering sentences such as: *"We have so many frogs! Can you get me the green one?"*; or *"Now, can you get me the crocodile?"*. Version V0.6.0 introduced: *"We have so many frogs! Can you get me the green one?. The green frog likes to hide in the green grass"*; or *"Now, can you get me the crocodile?. The crocodile is green. He looks like a lizard"*.

The robot informed the patient how many repetitions of an exercise were going to be done before starting. However, this was not implemented for the Toy Relay activity until version V0.11.0. As suggested by participants and therapists, the robot tells how many toys are going to be collected at the beginning of the activity in order to provide more information of the exercises to be done.

The robot delivered all the speech with the default voice values: accent, speed, and pitch. Altering the voice parameters, such as accent or pitch, can affect the child's perceptions of the robot [193]. For instance, a participant reported not liking the robot pronouncing their name incorrectly with a North American accent (the default English NAO's voice) in Phase 2 study. The availability of an Australian English language package ready to use could have solved this issue. We decided to not alter any of the default voice parameters due to the number variables to alter (speed and pitch) for a study where each participant interacts for a maximum of 3 sessions.

While misinterpretation of the robot's speech did not cause any system failure or major disruptions in sessions, it was observed that it could generate confusion among the patients. Participants in charge of the robot were told that if the robot seemed to not continue through the session, to tap the robot's head, which was generally programmed to make the robot carry on. While not considered an optimal solution, it was observed to provide a simple and intuitive interaction modality that robot operators could rely on.

4.1.2 Speech Recognition

Despite design decisions to optimise the robustness of NAO's built in speech recognition (see Section 3.3.5), verbal interaction with the SAR remained problematic. In early stages of the prototype development, it was identified that the speech recognition built into the

NAO robot was not suitable for our scenario. Most problematic was the young age of the patient participants, who often had difficulties coordinating turn-talking with the robot. Patients' responses were also often not loud enough to be processed reliably by the in-built natural language processing. The literature already documents issues related to the NAO robot speech recognition, which Phase 2 observations quickly confirmed [106, 170]. This was further exacerbated by other well documented challenges such as processing children's developing voices, as well as the impact of speech impediments which were commonly observed in this study's patient cohort.

Alternatives to the minimal speech recognition interaction were provided in early versions of the prototype (V0.1.0). For example, the speech of the robot was changed to inform the patient of the head tap option as well: *"Say Go or Tap my head when you are ready to start the next set"*. Notably, after this change, it was observed that most participants (physiotherapists, parents, and patients) stopped using voice commands.

Participants who still tried the speech recognition of the system were not aware if the robot understood the voice command, therefore, another prompt was provided after a speech recognition failure (V0.8.0). For example: *"Ooh, did you say something? Just tap my head to continue"*.

Observations indicated that participants (mostly physiotherapists and parents) seemed frustrated after consecutive failures of the speech recognition module. Limiting voice commands was thus deemed important to avoid unnecessary delays during the session, and to avoid undue frustration or other negative responses due to this limitation.

4.1.3 Tactile Interface

As noted, tactile button taps were observed to provide a reliable and preferred mode of interaction for both patients and therapists with the SAR. The inclusion of flashing LEDs marking the boundary of the head buttons was observed to reduce errors in precision, and confusion caused by missed taps observed in Phase 1. In particular, the continued flashing of the LEDs until a tap was registered provided sufficient guidance to participants to make another attempt if required, further supporting the SAR's *Integration* in the session, and *Stand-alone* operation.

The original prototype required engineer intervention in order to change the speed of an exercise in execution (explained in Section 4.2). To reduce this need, a tactile interface was developed (V0.9.0) using the head touch sensors (explained in detail in Section 3.3.7). The design of the tactile interface represented a trade-off between usability and misconfiguration errors due to its simplicity. Once the tactile interface became available, none of the participants needed to change the speed of an exercise, therefore its usability could not be evaluated. After pre-testing with research team's physiotherapist, the tactile interface was updated in order to simplify its usability. Instead of a double tap, it was changed to a single tap (V0.13.0). All patients were invited to use the tactile interface to proceed with the session (single tap in any of the head tactile sensors). However, system logs from a later session indicated that the repeated way of tapping the robot's head led to patients mistakenly adjusting the speed of an exercise.

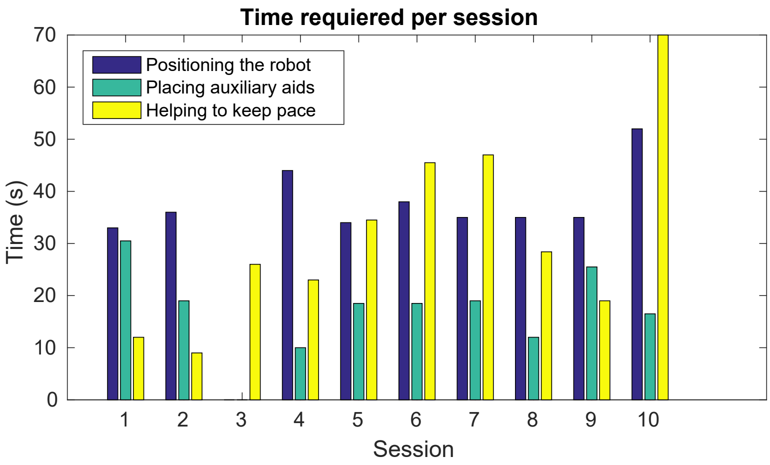
4.1.4 Human-Assisted Activities

Figure 4.1a provides a coarse-level analysis of time-costs associated with providing the SAR assistance over ten patient sessions in Phase 2. Figure 4.1b shows the corresponding number of occurrences of each activity, for each session. It can be seen that assisting the robot to keep pace (via head touch) required less time to perform, but occurred at significantly higher frequency than other human-assisted actions, scaling roughly with the number of activities to perform. While required often, Keeping Pace actions appeared to complement the general desire of patients to interact with the robot. Indeed, if close enough to the robot, and able, patients performed the action themselves. Therapist feedback indicated that allowing patients to deliver assistance to NAO also appeared to increase their activity and engagement during the session.

Positioning the Robot and Placing Auxiliary Aids occurred less frequently than Keeping Pace actions, but as expected, required more session time to perform. However, therapists expressed no concern with this time cost (less than one minute), and thus we consider the SAR's human-assistance needs to be within an acceptable limit. Notably, however, the exercise programmes observed in the current study involve a relatively low number of human-assisted exercises. It should be noted that other rehabilitation programmes may include a more diverse range of exercises that may require more carer assistance.

Physiotherapists participated in the study without any prior training, apart from being told that the SAR would ask for help from time-to-time. Therapists expressed willingness to provide assistance, and in general, demonstrated competence in handling the robot when required. A notable issue that was observed in early sessions was the therapist attempting to perform tasks for the robot that it was capable of itself. In particular, laying the robot on its back for exercises. Therapists were not explicitly told the SAR was capable of this itself, and thus understandably intervened. Improvements to the SAR's instructions during sessions, and more explicit statements of the SAR's capabilities during training should address this. In post session interviews, no concerns were expressed about the impact of the assistance they were required to provide. This is examined further in post study interviews in Chapter 6.

(a) Time.



(b) Occurrences.

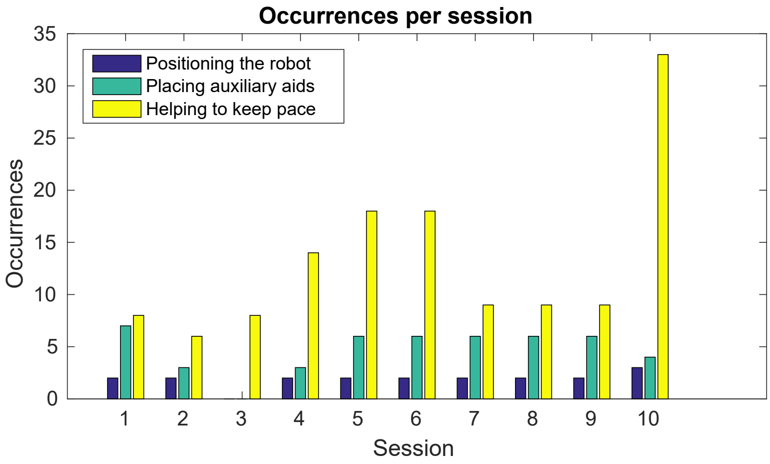


Figure 4.1: Time required and number of occurrences per session for human-assisted actions.

4.1.5 Posture Transitions

The robot executes different activities from different posture positions (standing up, crouching, laying down). It was observed very early (V0.1.0) that the robot should announce, and ask for supervision when transitioning between posture positions. This was to reduce possible falls that could damage the robot, and participant anxiety in case of falls.

Later in Phase 2, with more than 30 rehabilitation sessions delivered by the prototype, it was observed that the motors of the robot tended to overheat in sessions with more exercises or repetitions than an average session. This affected negatively the posture transitions, not allowing the robot to stand up at the end of the session and make it to lose stability. Researchers observed that such failures also impacted perceptions of the robot's competence and achievements. For example, in one session, participants applauded and celebrated the robot being able to stand up properly in their third session, after the robot not being able to do so in the previous sessions.

Based on such observations, the robot's ability to perform posture transitions itself was seen as important, but needed to be balanced with the need to ensure sessions were not disrupted by failures. Thus, the robot was programmed to attempt a posture change no more than twice. Beyond this limit, the robot asked participants for assistance in order to reach the new posture (V0.13.0). For example, the robot asks: *"Okay! I cannot stand up on my own. Can someone stand me up, please? And tap my head when I am ready!"*. Participants just had to flip the robot 90 degrees and tap the robot's head.

4.1.6 Exercise Order: Stability and Robustness versus Flexibility

The decision to fix the activity execution order during sessions was chosen to maintain *Stability* and *Robustness* requirements of the SAR by minimising posture and position changes. The low number of recorded system failures and technical interventions in Phase 2 testing supports this decision (Explained in Section 4.2), with system failures mostly occurring during a dance (entertainment) scenario, when changing posture (e.g. standing), and due to power loss (see Table A.1). However, *Flexibility* is compromised, and the inability to dynamically change exercise execution order was raised as a deficit of the current system design by therapists. Early feedback in Phase 2 from a therapist suggested the robot could ask the patient which exercise to do next, instead of following a prescribed order. Such flexibility can be considered within particular exercise subsets. For example, the system may allow therapists (or patients) to change execution order within a specific block of lower body exercises.

4.1.7 Logfile and Sonar

The robot being able to self-log system information (V0.3.0) enabled recording of the length of sessions, the exercises performed, the speech delivered, and participants' interactions via button taps. In order to study how the robot could improve its interaction during the Toy Relay game, the NAO's ultrasonic depth sensor data also started being logged during the activity (V0.11.0). This depth data was subsequently analysed for possible use in the robot's feedback to patients. While clear patterns detecting the proximity of the participants were evident, the variable orientation of the robot during the exercise, as well as sources of false detection such as assisting physiotherapists or siblings made the reliable detection and monitoring of patient movement in the task challenging.

The sonar data was thus not utilised in this study. However, with the data logged, future work will consider the possible use of sonar acquired depth data to enhance feedback during this (and possibly other) exercises and activities.

4.1.8 Configurability via Tablet Interface

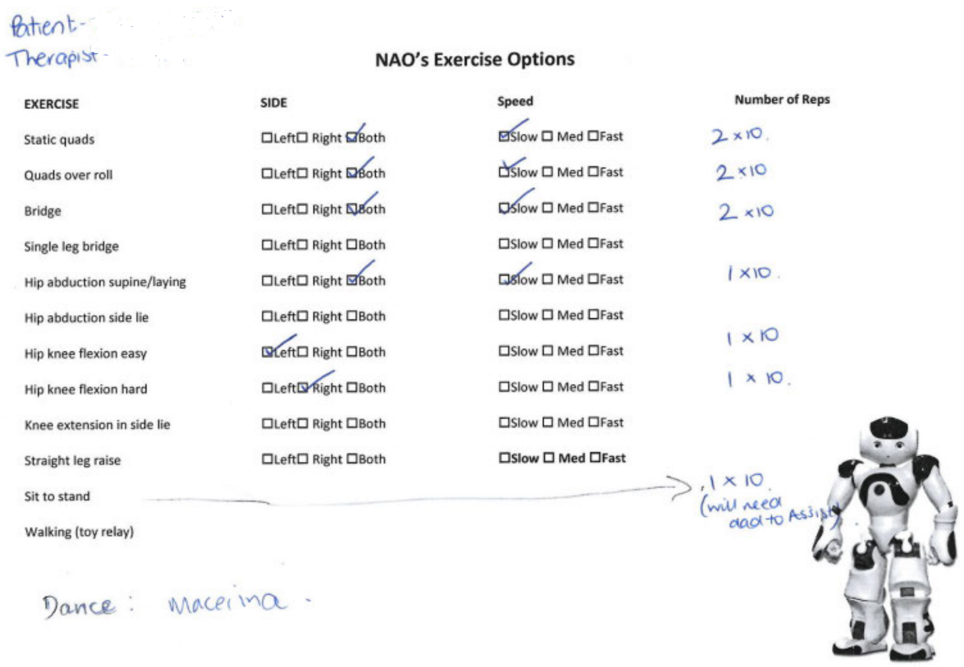
The SAR software was designed to support rapid configuration for new exercise sessions, allowing for the pre-selection and scheduling of exercises to perform, number of repetitions, speed of execution, entertainment modules, as well as patient and physiotherapist names. Configuration time was observed to take no more than 5 minutes, however, the configuration interface in Phase 2 was text-based (ROS actionlib axclient.py) and thus not directly usable by therapists. Instead, physiotherapists sent a form to the research engineer with the minimum information required to programme the session (an example is shown in Figure 4.2a).

This, however, was not ideal, with therapists indicating the desire for a more user-friendly and flexible configuration process. To address this, a tablet-based interface was developed by a group of Masters students from Melbourne University following the specifications outlined by myself and the research team's physiotherapist.

The tablet interface provided therapists a tool to configure and start the robot programme themselves, it was designed as a web application to allow the operation of the robot from any device (tablet, mobile phone, laptop or desktop). The web app based on Django and Angular is hosted on the server where the code of the robot is executed (explained in Section 3.2). Thus, the developed web app does not enter into conflict with the NAO web page of the robot. The "Execute" button from the web app calls the ROS actionlib client interface to send the rehabilitation programme to the robot and to start the rehabilitation session. GNU/Linux services running all the basic ROS modules can also be restarted from the web app for debugging purposes. The web app is designed to work for the software developed in ROS for the NAO robot. Portability of the app to other robots (e.g., Pepper) is easily achieved through simple modifications to the ROS code.

Therapists were able to save in the web app different patients' sessions configuring the exercises, number of sets, repetitions, and interactive modules. Sessions stored in the app could be modified and executed later from the very beginning, or from a middle point in case a session needed to be restarted. As shown in Figure 4.2b, the tablet interface is used to configure and initiate the session, after which robot control is only possible via robot interactions as already outlined.

The therapist's interface was developed in parallel during Phase 2, and became available at the end of the Phase 2 study (V0.14.0). Specifically, the interface was introduced



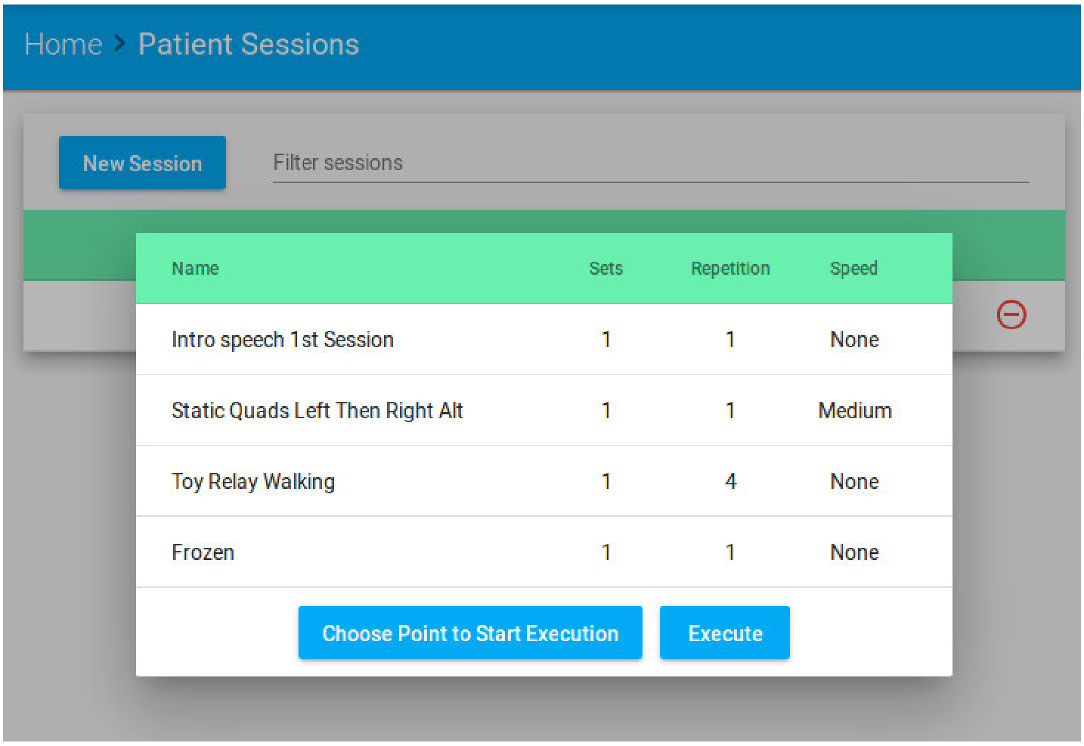
Patient -
Therapist -

NAO's Exercise Options

EXERCISE	SIDE	Speed	Number of Reps
Static quads	☐Left☐ Right ☑Both	☑Slow ☐ Med ☐Fast	2 × 10.
Quads over roll	☐Left☐ Right ☑Both	☑Slow ☐ Med ☐Fast	2 × 10
Bridge	☐Left☐ Right ☑Both	☑Slow ☐ Med ☐Fast	2 × 10
Single leg bridge	☐Left☐ Right ☐Both	☐Slow ☐ Med ☐Fast	
Hip abduction supine/laying	☐Left☐ Right ☑Both	☑Slow ☐ Med ☐Fast	1 × 10.
Hip abduction side lie	☐Left☐ Right ☐Both	☐Slow ☐ Med ☐Fast	
Hip knee flexion easy	☑Left☐ Right ☐Both	☐Slow ☐ Med ☐Fast	1 × 10
Hip knee flexion hard	☐Left☑ Right ☐Both	☐Slow ☐ Med ☐Fast	1 × 10.
Knee extension in side lie	☐Left☐ Right ☐Both	☐Slow ☐ Med ☐Fast	
Straight leg raise	☐Left☐ Right ☐Both	☐Slow ☐ Med ☐Fast	
Sit to stand			1 × 10. (will need dad to Assist)
Walking (toy relay)			

Dance : Maceina -

(a) Session's form.



Name	Sets	Repetition	Speed
Intro speech 1st Session	1	1	None
Static Quads Left Then Right Alt	1	1	Medium
Toy Relay Walking	1	4	None
Frozen	1	1	None

(b) Tablet Interface.

Figure 4.2: (a) Physiotherapist's form to configure a rehabilitation session. (b) Tablet interface which replaced the session's form.

into the 3 last sessions of Phase 2, and was used during Phase 3.

A formal evaluation of the tablet interface is not in the scope of this thesis, however, it was observed to improve the perceived accessibility of the robot, including allowing the SAR to be utilised voluntarily in sessions after the completion of Phase 2. The identification of its need, and the functional requirements it fulfilled for the trial was therefore seen as a significant outcome of the Phase 2 development phase.

4.1.9 Exercise Incorporation

As patient sessions progressed, new activity scenarios were incorporated into the system during the Phase 2 study. Examples are the different introductory speeches for different sessions with the same patient. Participants did a maximum of 3 sessions, and so in order to reduce repetition over multiple sessions, two more session introductions were included (V0.2.0 and V0.3.0). In preparation for an evaluation of the robot in daily use, 4 more speeches were incorporated at the end of Phase 2 (V1.0.0).

The Toy Relay activity was incorporated into prototype version V0.2.0, and the sit-to-stand exercise in V0.3.0. Due to an observed high risk of failure of doing the sit-to-stand exercise with a seat (as explained in Section 3.3.2), it was changed to do it by crouching. Sit-to-stand by crouching is a much more stable version and less prone to falls than sit-to-stand with the seat (V0.4.0). It also removed the need for an extra piece of equipment (the seat), which was observed to be important for the system's general portability around the hospital. The demonstration of the sit-to-stand exercise was improved at the end of the study (V1.0.0), clarifying that patients have to tap once for the robot to stand it up, and tap the robot once again to sit it down. The Hip Extension Easy and Hard exercises became fully available with demonstrations by the end of the study (V1.0.0).

Two new dance routines were incorporated into the system, one programmed by a physiotherapist (V0.8.0), and one by a medical student (V0.10.0) who were part of the research team. The ability of non-technical team members to programme such additional entertainment modules with relative ease was observed to be useful feature of the both the visual programming language Choregraphe that comes with the NAO robot SDK, and also of the underlying modular architecture of the system which deliberately allowed for such flexibility and extendability.

4.2 System Performance Evaluation

This section reports on directly measured outcomes from the Phase 2 trial relating to delivering therapy sessions with the SAR. This includes the patient's compliance with the prescribed activities and the system's performance in terms of session disruptions caused by software errors or hardware limitations which required technical support. Table A.1 in Appendix A provides a structured overview of the 41 sessions, these sessions are discussed with respect to the major themes of system evaluation below.

4.2.1 Exercise Completion

Overall, almost (37) all the 41 rehabilitation sessions (90%) delivered by the robot ended with patients completing all their prescribed exercises. Sessions lasted, on average, 28m 0s ± 10m 26s and were scheduled with 2 - 7 exercises.

In 34 sessions, patients expressed positive attitudes towards the robot such as excitement and enjoyment, focusing on the robot during the exercises. Sessions not completed involved a range of causes:

Session 4: a teenage patient expressed a clear dislike of the robot, invoking a premature stop to the session.

Session 23: the Toy Relay activity was aborted due to the patient's perceived lack of stamina, as judged by the attending physiotherapist.

Session 31: two exercises were completed partially by the patient in due to the patient's lack of compliance.

Session 37: Due to a system update not completed correctly, the Sit-to-Stands exercise was not executed.

More extended analysis of how patients worked with the robot is presented in Chapter 5.

4.2.2 System Disruptions

Seventeen of the 41 sessions (42%) recorded different system disruptions. Rehabilitation sessions run without any backup support such as a second robot, a second laptop, alternative access point, or a battery replacement. In total, engineer intervention was required in 12 of the 41 sessions (29%). Below we describe the causes of disruptions in more detail.

Figure 4.3 provides a summary per session of all system disruptions occurred indicating if engineer intervention was required or the robot self recovered. The plot also indicates the cause of disruption during the session.

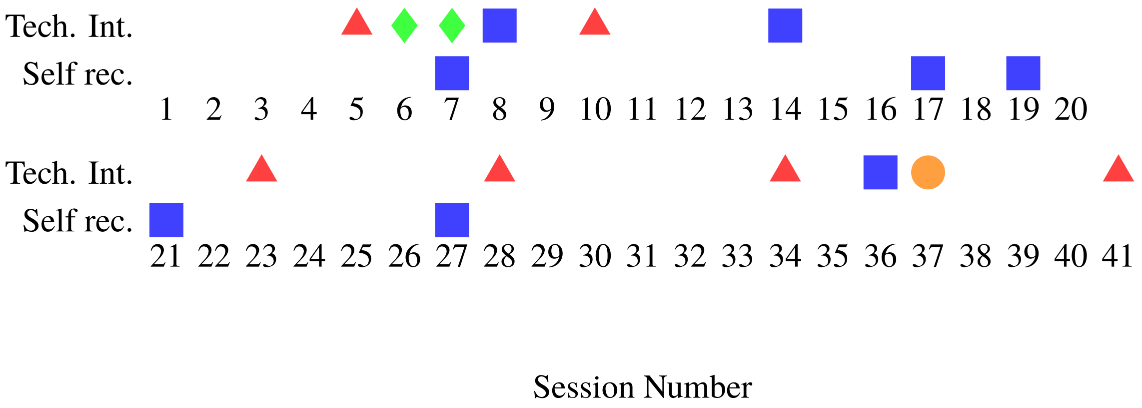


Figure 4.3: Summary of system disruptions indicating per each session if technical intervention (Tech. Int.) was required or the robot recovered itself (Self rec.). Blue squares indicate system disruptions due to stability loss; red triangles indicate human errors; green diamonds are technical interventions due to online reconfiguration; and the orange circle indicates a disruption due to recent updates into the system.

Stability Loss

In 5 sessions (7, 17, 19, 21, and 27) the robot lost stability when trying to stand up, however, demonstrated self-recovery without researcher intervention, and was able to successfully stand on the second attempt. In Sessions 8 and 36 the robot fell while trying to stand up, however, self-recovery failed and intervention was required to restart the system. Observations indicated that the greater number of exercises performed (6 and 7 exercises when the average was 4.5), and the length of the sessions (46m 31s, and 42m 28s when the average was 28 minutes) overheated the motors and self-recovery did not succeeded. As explained in Section 4.1.5, the robot explicitly asks for assistance from participants when the number of self-recovery attempts reaches certain threshold (set to 3 by default) to prevent technical interventions (V0.13.0). However, the best way to prevent such disruptions would be constantly monitoring the temperature of the motors during execution time. The robot itself would be able to gauge if it is safe to execute certain movements, and then act accordingly. For instance, executing less over-stressing movements or asking directly for help to attain certain postures.

Robot falls during the final dance routine were common, however, those falls happened at the very end of the session, and thus had no effect on the care delivery itself. However, more conservative robot movements, or placing of the robot on more stable surfaces was recommended to prevent such falls. During the Toy Relay activity in Session 14, the patient stumbled onto the robot, thus requiring engineer intervention to restart the system. Due to the possibility of a system reboot being needed, the tablet interface (as discussed in

Section 4.1.8) introduced later in Phase 2 allowed therapists/parents to reboot the system themselves.

Human Errors

Three sessions (5, 23 and 34) had a loss of power to the robot and so required engineer intervention to resolve. Reasons for the power loss were most commonly due to battery discharge caused by longer than normal periods of use. This was due to consecutive sessions, longer sessions, or unsuccessful between-sessions recharging due to human error. The NAO robot announces when its battery level is about to be empty, however, an improvement would be the robot monitoring itself the battery level before and throughout the rehabilitation session. This would allow the robot to estimate how many exercises can perform before it needs to be plugged, and avoid unnecessary disruptions.

From experience in this study, a fully charged NAO robot can reliably support up to 45 minutes of intensive rehabilitation.

Session 10 and 41 required re-configuration by the attending engineer due to wrong or an altered configuration of the session. Prior to the introduction of the tablet interface, therapists were unable to configure the robot themselves, as explained in Section 4.1.8.

Limited familiarity and experience operating the robot was also observed to be a source of disruptions in the session. For instance, a physiotherapist, who operated the robot for the first time, tilted the robot in order to lay it down in Session 28. The tilt of the robot activated the robot's fall manager, triggering a self-enforced "stiffness-off" command to cushion the fall, requiring engineer support to recover. The robot's fall manager is crucial to its ability to detect and self recover from falls, however was also observed to complicate such physical handling of the robot during sessions. Future iterations of the software design will seek to more selectively apply the fall manager, perhaps turning it off when asking to be helped. More explicit training to educate participants in handling the robot would also mitigate this issue, although would be unlikely to completely remove such events.

Online Reconfiguration

Two early sessions (6 and 7) required engineer intervention to change the speed of an exercise. In Session 6, this was required to slow down an exercise, and in Session 7, to speed it up. The tactile interface that allowed participants to alter the speed of an exercises was ready for deployment in Session 15 (Explained in Section 4.1.3). While no further need for such online adjustments were observed, this may have been because therapists became more familiar with the robot's speed of execution and thus were better equipped to judge the speed required.

Software Updates

Session 37 had a serious system failure such that engineer intervention was required several times. Further post-session investigation indicated that an update of the SAR system activated the “Animation mode” of the NAO robot, causing half of the robot to be unstiffened during the session. This was a generally observed risk, inherent to the iterative design process adopted, in which software updates, and new movement transitions or new exercises (Section 4.1.5 and Section 4.1.9), exposed the system to higher risk of software failures.

4.3 Summary

This chapter explained how the iterative development of the SAR prototype has addressed some issues raised by participants and observation notes. It also reported on the operational performance of the robot in the 41 rehabilitation sessions of the Phase 2 study.

The prototype has gone though 25 different versions in 2 years until it reached the version 1.0.1 used in the last study of this thesis, presented in Chapter 7. The main improvements and modifications of the prototype such as the robot’s speech delivery, and interaction capabilities have been reported here.

Robustness and Endurance were important requirements deemed by all the stakeholders during the initial phase of the project (Section 3.1.8). Thus, the robustness of the system when delivering rehabilitation sessions is an important aspect to consider, especially if integrating a SAR to be used by non-technical users in a hospital environment.

Of the 41 rehabilitation sessions performed during Phase 2 study, 17 had some sort of system disruptions. However, the robot was able to self-recover in 5 sessions, such that only 12 sessions required technical intervention. Most of the interventions were required due to falls, and human errors such as misconfigurations or battery drainage. The chapter also explained how the 12 system disruptions, in which engineer intervention was required, have been addressed in order to reduce the need for technical intervention in future testing and deployment of the robot. System disruptions due to falls were reduced in the last sessions of the study due to iteratively improving the robotic prototype. However, a clear disadvantage of the in situ evaluation has been the exposure of those system disruptions to the participants.

While the system’s technical performance is an important factor to consider in order to integrate a SAR in a hospital setting, the acceptance of the new technology by the final end users is a crucial aspect to evaluate. The next chapter presents a formal evaluation of the prototype in terms of participants’ perceptions after delivering 41 rehabilitation sessions, and discusses these user perception results in the context of the system performance results highlighted in this chapter.

Chapter 5

User Acceptance Evaluation

Previously, Chapter 3 presented the three-phase in situ design process in order to develop and evaluate a Socially Assistive Robot (SAR) as a therapeutic aid for paediatric rehabilitation. Frequent stakeholder engagement in the initial phase of the project (Phase 1) guided the derivation of a basic set of roles and requirements for a social robot for ongoing clinical deployment. Based on the derived roles and requirements, I implemented the first robot prototype which was equipped to lead rehabilitation sessions of up to 30 minutes under the assistance of an adult, with minimal technical support requirements and no Wizard-of-Oz operation.

In Chapter 4, the prototype modifications performed during the iterative development and in situ testing in the hospital were presented, as part of Phase 2. Results on the system performance of the robot over these sessions was also reported. While technical performance is an important factor to be considered when exploring the integration of a SAR for ongoing clinical deployment, the acceptance of the robot by the primary users when delivering rehabilitation is the most crucial aspect to consider. If the new technology is not accepted by the primary users, or it causes more inconveniences than benefits, final users will reject it [158].

This chapter evaluates participants' perceptions of the prototype SAR as a therapeutic aid. Specifically, this chapter reports participants' acceptance and perceptions of the robot in the context of delivering paediatric rehabilitation during this formal evaluation in Phase 2, spanning sessions from May 2016 to November 2017. Quantitative and qualitative data collected from all the participants groups are reported: therapists, parents and patients, across 41 rehabilitation sessions. In later chapters, these results are contrasted with post-Phase 2 interviews, and case studies obtained during Phase 3 integration testing on-ward.

This chapter is structured as follows. Section 5.1 outlines the methodology of the study to evaluate the SAR, providing an overview of the trial environment, participants, method, and data collected. Acceptance questionnaire results and discussion are presented in Section 5.2. The Godspeed questionnaire results which provide other insights in the evaluation of the SAR are presented in Section 5.3. Open ended questions are presented and discussed in Section 5.4. Finally, Section 5.6 provides a summary of this chapter and the broader implications for the development of the SAR for clinical deployment.

5.1 Method

From August 2016 to November 2017 the prototype SAR was evaluated for paediatric rehabilitation, as part of the prescribed rehabilitation programme of patients with a range of rehabilitation needs. Previously, Section 3.4 presented the trial environment of the Phase 2 study carried out in a one-way mirrored consultation room. Figure 5.1 shows the hospital set-up used in this study.

Below the participant recruitment, session procedure, measures, and data collection for the study are presented.

5.1.1 Participant Recruitment

Patients, parents and therapists were all formally recruited to participate in this study, with ethics clearance obtained from both partner institutions: The Royal Children's Hospital Melbourne Human Research Ethics Committee (HREC 36128C); and Swinburne's Human Research Ethics Committee (SUHREC Project No: 2016/202). Ethics clearance from both partner institutions are provided in Appendix B.

The inclusion criteria for patients were that they had been prescribed a rehabilitation programme consistent with the SAR's predominantly lower-limb exercise capabilities (due to focus on cerebral palsy rehabilitation needs), and based on physiotherapist clinical judgement. Table 5.1 gives a summary of the number of patients who consented to participate in the study indicating their gender, age, number of sessions with the robot, and their medical condition. The most common medical conditions encountered are described in Subsection 2.1.1.

Informed consent was obtained from all parents (on behalf of themselves and their child) and physiotherapists participating in the study. Patients with enough level of under-

Figure 5.1: Study setting. Upper image: Participants' room with a one-way mirror. Lower image: Observation room.

standing and maturity, based on physiotherapist's clinical judgements, also consented to participate. Once consent was obtained, physiotherapists scheduled a rehabilitation session with the robot and their treating physiotherapist. If the treating physiotherapist was a member of the research team, the research team member operated the SAR for the patient but no data from the therapist was recorded.

After completing a session, participants were given the option to participate in another session. Invitations to continue were given regardless of the observed success of the session, and were not influenced by survey responses after the session. If agreed to, the attending parent was invited to operate the robot themselves without a physiotherapist present. Different versions of the surveys were used depending on if the parent observed only, or operated the robot during the session. The exclusion criteria for parents operating

Table 5.1: Patient participants.

No	Gender	Age	Sessions	Diagnosis	Rehab Reason
P-1	Female	7	3	Spina Bifida	SEMLS
P-2	Female	13	1	CP / ID /ASD	Spinal fusion
P-3	Female	16	1	Secondary SCI	Tune up
P-4	Male	6	3	CP GMFCS IV, quadriplegia	SEMLS/SDR
P-5	Female	10	1	CP GMFCS III, diplegia	Tune up
P-6	Male	12	1	CP GMFCS II, diplegia	SEMLS
P-7	Female	15	1	Elhers danlos syndrome	Tune up
P-8	Male	15	1	CP GMFCS II, diplegia	SEMLS
P-9	Male	5	3	Stroke, Right hemiplegia	Stroke
P-10	Female	10	3	Primary dystonia	Functional decline
P-11	Male	9	3	CP GMFCS II, diplegia	SEMLS
P-12	Male	10	2	CP GMFCS III, diplegia	SEMLS
P-13	Male	9	3	CP GMFCS III, diplegia	Post SEMLS
P-14	Female	13	2	SCI incomplete	SCI
P-15	Male	5	2	CP GFMCS II, left hemiplegia	Post Botox
P-16	Male	7	3	CP GMFCS II, diplegia	SDR
P-17	Female	8	2	SCI incomplete	SCI
P-18	Male	10	3	Hemiconvulsion-Hemiplegia-Epilepsy Syndrome	Hemispherectomy
P-19	Female	6	2	Hereditory spastic paraparesis	Post Botox
P-20	Male	9	1	Williams syndrome	Spinal fusion

the system were parents with restricted mobility, parents of children with highly impaired mobility (e.g. GMFCS IV), and physiotherapist clinical judgement (based on needs of the patient). A parent with restricted mobility, and another parent of a child with highly impaired mobility were excluded. Three parents were not available to participate in a further session.

5.1.2 Session Procedure

The research engineer (author of this thesis) was responsible for system setup prior to patient arrival. Two NAO robots were used in this study: a royal blue NAO robot version 5 which delivered the first 4 rehabilitation sessions, and a teal blue NAO robot version 4 which delivered the rest of the sessions.

The setup consisted of booting up the NAO robot and a laptop, establishing a wireless connection between those two devices, launching all the Robot Operating System software modules including the rehabilitation programme, and sending the patient's specific rehabilitation programme to the robotic system. The setup of the system normally took 5 minutes if no errors were encountered. Errors during the setup were normally caused by problems when establishing the wireless connection between the laptop and the robot, or errors when launching the Robot Operating System software modules.

The Research Therapist (a senior physiotherapist who was a member of the research team) was responsible for recruiting patients with a suitable rehabilitation programme for the robot, and introducing and instructing caregivers to use the SAR prior to their first session. The Research Therapist explained that the robot would follow the prescribed programme autonomously, but would occasionally request help as required, and request head button taps to confirm readiness at various stages. Participants were also told the system was capable of recovering from falls without intervention.

Once running, the robot indicated readiness by stating: *"I am going to wait until someone taps my head."* At this point all research team members left the room.

Only in cases of major disruption did the Research Therapist enter the Participant Room after session commencement. Such cases of major disruption were outlined in Section 4.2.

5.1.3 Measures

In order to evaluate the participants' perceptions of the SAR self-report measures were gathered after their interaction with the robot. Observations were also gathered via annotations by researchers in the Observation Room. Observations together with system logs complemented the participants' self-report surveys.

All surveys used in this study are provided in Appendix C. Surveys were composed of three parts: Acceptance Questionnaire, Godspeed Questionnaire, and Open Questions. Each of these is detailed below.

Acceptance Questionnaire

A modification of the 'Acceptance of an assistive social robot' questionnaire, developed by Heerink et al. [85], was included in the survey. The Acceptance Questionnaire is further explained in Subsection 2.4.1. While originally designed for the elderly care context, for this study the questionnaire was adapted to be relevant to the paediatric health care context, and was further customised for the 3 primary user groups: therapists, parents and patients.

Table 5.2 shows acceptance survey items asked to physiotherapists. The questionnaire is divided into different categories: Anxiety (ANX1, ANX2), Attitude (ATT), Facilitating Conditions (FC), Intention to Use (ITU), Perceived Adaptability (PAD), Perceived Ease of Use (PEOU), Perceived Usefulness (PU), Trust (TR) and Social Influence (SI). The Anxiety category originally was composed of 4 items which mixed anxiety of being afraid or scared of the robot, and anxiety of not being competent and making mistakes when using the robot. Different strategies can be adopted in order to reduce those two different types of anxiety. For instance, more training might reduce the levels of anxiety for not

Table 5.2: Acceptance questionnaire for physiotherapists.

Construct	No	Question
ANX1	1	I would be afraid to make mistakes using the robot
	2	I would be afraid to break something when using the robot
ANX2	3	I find the robot scary
	4	I find the robot intimidating
ATT	5	I think it's a good idea to use the robot
	6	The robot would make therapy sessions more interesting
FC	7	I have everything I need to make good use of the robot
	8	I know enough of the robot to make good use of it
ITU	9	If I have access to the robot, I think I'll use it during the next therapy sessions
	10	If I have access to the robot, I am certain to use it in the next therapy sessions
	11	If I have access to the robot, I'm planning to use it during the next therapy sessions
PAD	12	I think the robot can be adaptive to what I need
	13	I think the robot will only do what I need at that particular moment
	14	I think the robot will help me when I consider it to be necessary
PEOU	15	I think I will know quickly how to use the robot
	16	I find the robot easy to use
	17	I think I will be able to use the robot without any help if I have been trained
	18	I think I will be able to use the robot when there is someone around to help me
	19	I think I will be able to use the robot when I have a good manual
PU	20	I think the robot is useful to help in paediatric therapy
	21	It would be convenient to have the robot for therapy sessions with kids
	22	I think the robot can help me with many things during paediatric sessions
SI	23	I think the staff would like me using the robot
	24	I think parents would like me using the robot
	25	I think patients would like me using the robot
	26	I think it would give a good impression if I should use the robot
TR	27	I would trust the robot if it gave me advice
	28	I would follow the advice the robot gives me

being competent with the robot, but will not necessarily reduce anxiety levels arising from being scared of the robot. Therefore, the Anxiety category was divided in two parts to better understand the extent to which participants were anxious about the robot itself (eg., safety), versus their ability to use the system without background knowledge (eg., risk of breakage, or usage error).

The Acceptance questionnaire for parents included fewer items, as shown in (Table 5.3). Items were formulated in plain language, and items deemed less relevant for parents were removed to minimise the time required of them to fill out the survey. The constructs removed were: Intention to Use (ITU), Perceived Adaptability (PAD), and Social Influence (SI). As parents are generally not experts in delivering physiotherapy, or concerned with the development of the SAR, the Intention To Use category was removed. In this study, parents essentially observed physiotherapists deliver rehabilitation to their child with the robot, and few of them had the chance to operate the robot themselves. Thus, Perceived Adaptability (PAD) and Social Influence (SI) constructs were also not considered relevant to their roles as observers.

Table 5.3: Acceptance questionnaire for Parents/Guardians.

Construct	No	Question
ANX1	1	I would be afraid to make mistakes using the robot
	2	I would be afraid to break something when using the robot
ANX2	3	I find the robot scary
	4	I find the robot intimidating
ATT	5	I think it's a good idea to use the robot
	6	The robot would make my child's rehab sessions more interesting
FC	7	I have everything I need to make good use of the robot
	8	I know enough of the robot to make good use of it
PEOU	9	I think I will know quickly how to use the robot
	10	I find the robot easy to use
	11	I think I can use the robot without any help
	12	I think I can use the robot when there is someone around to help me
	13	I think I can use the robot when I have a good manual
PU	14	I think the robot is useful for paediatric rehabilitation
	15	It would be convenient to have the robot for therapy sessions together with the physiotherapist
	16	It would be convenient to have the robot for therapy sessions when the physiotherapist is not in the session
	17	I think the robot can help my child with many things
TR	18	I would trust the robot if it gave me advice
	19	I would follow the advice the robot gives me

Table 5.4: Acceptance questionnaire for Patients.

Construct	No	Question
ANX2	1	I find the robot scary
	2	I find the robot intimidating
ATT	3	I think it's a good idea to use the robot
	4	The robot would make my exercises more interesting
	5	It's good to make use of the robot
PENJ	6	I enjoy the robot talking to me
	7	I enjoy doing things with the robot
	8	The robot is fun
	9	I find the robot boring
PS	10	I consider the robot is friendly
	11	I feel the robot understands me
	12	I think the robot is nice
PU	13	I think the robot should keep coming to my sessions
	14	I think the robot will help me if he comes to my exercise session
	15	I think the robot can help me with many things
SP	16	When talking with the robot I felt like I'm talking to a real person
	17	It sometimes felt as if the robot was really looking at me
	18	I can imagine the robot to be a living creature
	19	I often think the robot is not a real person
	20	Sometimes the robot seems to have real feelings
TR	21	I would trust the robot if it gave me advice
	22	I would trust the robot more than the physiotherapist if he told me what to do
	23	I would trust the robot more than my parents if he told me what to do
	24	I would follow the advice the robot gives me

Table 5.4 shows the Acceptance questionnaire asked to patients. In contrast to physiotherapists and parents, patients are the primary focus of the robot's social interaction and care delivery. Hence, questions to patients, rather than focusing on Facilitating Conditions (FC) or Perceived Ease of Use (PEOU) of the system, target the patients' perception of the robot's interactiveness through categories such as Perceived Enjoyment (PENJ), Perceived Sociability (PS), and Social Presence (SP). Patients were also asked questions about their thoughts on the robot's usefulness (PU), the extent to which having the robot in their rehabilitation sessions was a good idea (ATT), and also the extent of anxiety they felt towards the robot (ANX2). The Trust construct (TR) also included two extra questions comparing their trust of the robot's advice compared with advice from their parents or physiotherapists. Patients had fewer items than physiotherapists with items formulated in plain language for ease of understanding.

Items were formulated as statements to be rated using a Likert scale (*Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree*). Items were presented in randomised order. Results of the Acceptance questionnaire are reported in Section 5.2

Godspeed Questionnaire

The second part of the survey comprised the Godspeed questionnaire [8], and was presented to all participants without modification. This questionnaire is composed of 23 semantic differential scale items to measure perceptions of the robot in terms of Anthropomorphism (ANTH), Animacy (ANM), Likeability (LIKE), Perceived Intelligence (PeIn), and Perceived Safety (PS). The Godspeed questionnaire has been previously introduced in Subsection 2.4.1, page 41.

This questionnaire is widely used in the Human-Robot Interaction community to gauge perceptions of social robots in general. While the modification of Heerink's questionnaire provides measures of the participants' acceptance of the robot, Bartneck's questionnaire provides direct measures of how likeable the robot is (LIKE), its perceived intelligence or competence in its task (PeIn), and the robot's animacy (ANIM) or robot's responsiveness.

In order to mask the intention of the questionnaire, the order of the items were randomised and two dummy items were included in the questionnaire (Pessimistic - Optimistic; Tired - Energetic) as suggested by the authors of the questionnaire. Results of the Godspeed questionnaire are reported in Section 5.3

Open Questions

Open ended feedback was obtained from therapists, parents, and patients. Participants were asked to comment on possible system improvements, any issues or problems encountered, and patient compliance and emotional state during the session. Parents who operated the robot in a session were also asked about their confidence when interacting with the robot. Open ended questions also provided participants the opportunity to further explain their experience with the robot for better understanding of their survey responses, and also to capture questions not covered in the survey. Participants' experiences with the robot, possible system improvements, and features that they liked or disliked were also collected for future development of the SAR for ongoing clinical deployment. The list of open questions for therapists, parents (operating and observing) and patients are provided respectively below.

Open ended questions for physiotherapists

- What do you think is missing in the robot to be a useful legitimate aid tool?
- Which role (demonstrator/motivator/companion/coach/other) of the robot has attracted you most and/or least. Why?
- Which is the most important feature that should be fixed/implemented as soon as possible in the robot?
- How would you rate this child in this session?
- Is there anything else that you would like to say about the robot or the session?

Open ended questions for parents observing a session

The open questions for parents were different if they observed a session, or they operated the robot. The open questions after observing a session are the following:

- Do you think the robot was useful for this rehabilitation session? Why?
- Given the opportunity and some training, would you be prepared to use the robot without a physiotherapist present?
- What things about the robot could be added, changed or fixed to make the robot more useful to you and your child's rehabilitation?
- What things about the robot don't you like? Why?
- Is there anything else that you would like to say about the robot or the session?

Open ended questions for parents operating the robot

The open questions asked parents to reflect on their experience after operating the robot:

- How confident did you feel about operating the robot when a therapist was not present?
- To what extent did you feel the attention you needed to give the robot impacted on the level of attention/assistance you could give to your child?
- To use the robot independently what training would you need? What things about the robot could be added, changed or fixed?
- Did operating the robot improve your trust in the system? Why?
- In what ways (if any) do you believe the robot assists your child whilst in hospital or a therapy session?

Open ended questions for patients

- Would you like to do another session with the robot? Why?
- What is the thing you like the most about the robot? Why?
- Is there anything that you don't like about the robot?
- What extra things would you like the robot to do?
- Is there anything else that you would like to say about the robot or the session?

Open ended responses are reported in Section 5.4

5.1.4 Data Collection

Data was collected from 8 therapists (6 fully qualified physiotherapists, 2 physiotherapist trainees). Therapists completed a total of 19 surveys (Appendix C.1) after each rehabilitation session. Table 5.5 shows the number of surveys collected by each physiotherapist.

Twenty parents were recruited to participate in rehabilitation sessions with their child, using the robot. After each session, parents filled in the survey (provided in Appendix C.2). While all parents participated as observers in the first session, eight of the twenty parents were also invited to operate the SAR themselves in additional sessions. In these sessions, parents filled in the survey again after operating the robot. The survey for parents after

Table 5.5: Number of sessions delivered by physiotherapist.

Physio	Category	Gender	Surveys Collected
A	Qualified	Female	2
B	Qualified	Female	4
C	Qualified	Female	3
D	Qualified	Female	4
E	Qualified	Female	2
F	Trainee	Female	2
G	Qualified	Female	1
H	Trainee	Female	1

operating the robot (Appendix C.3) only differs from the survey for parents observing only in terms of the open questions, in which are additionally asked to reflect on their experience after operating the robot. If parents observed a session for a second time and filled in a second survey, the open ended responses were only used for the analysis if they provided different responses than the first survey.

Patients deemed cognitively suitable by the therapists and parents to comprehend the survey completed the questionnaire (Appendix C.4) after the first rehabilitation session. Fifteen out of 20 patients provided feedback after completion of their rehabilitation session with the robot. Thirteen of these competed the full survey and open questions, while 2 only provided open question responses with the help of physiotherapists who transcribed their responses. To not bias the study towards positive responses of patients who liked the robot, only the open ended responses of second surveys were included in the analysis if they provided different responses. Patients' quantitative data of later sessions were not considered for the analysis of the results.

Table 5.6 shows a summary of responses of the surveys collected during Phase 2 study. The first column identifies the patient, the next 3 columns indicate the number of the session. Each Session column has 3 subcolumns indicating the participant category: PT (Physiotherapists), G (Guardian or Parents), and P (Patients). The number in each cell indicates the number of surveys collected. Empty cells indicate no surveys were collected. For example, in the first session of Patient 1 (P-1), two surveys were collected because both parents attended. The physiotherapists who operated the robot in the first session of Patient 1 (P-1) was the Research Therapist, so survey data was not collected; the patient also filled in the survey in that session.

Parents mostly observed physiotherapists deliver rehabilitation with the robot to their child. However, those parents who operated the robot and filled in the survey are a special category indicated with an asterisk (eg., 1*).

Red cells indicate surveys that were not able to be collected. Examples of those are: the physiotherapist's survey in the first session of Patient 8 (P-8), in which the physiotherapist

Table 5.6: Summary of responses of surveys collected during Phase 2 study. Columns indicate the patient, and the sessions done for each patient. Three sub-colums for each session indicate participant survey: physiotherapist (PT), parents or guardians (G), and patients (P). The number in each cell indicates the number of surveys collected, parents who operated the robot are indicated with an asterisk. Red cells indicate surveys not collected, yellow cells indicate open ended survey questions used only.

	Session 1			Session 2			Session 3		
Patient	**PT**	**G**	**P**	**PT**	**G**	**P**	**PT**	**G**	**P**
P-1		2	1	2			1		1
P-2	1	1							
P-3	1	1	1						
P-4		1						1	
P-5	1	1	1						
P-6	1	1	1						
P-7		1	1						
P-8	1	1	1						
P-9	1	1					1	1*	
P-10	1		1				1	1	1
P-11	1	1	1					1*	1
P-12	1	1	1		1*	1			
P-13	1	1	1		1*	1	1	1	1
P-14		1	1		1*	1			
P-15		1							
P-16	1	2	1		1	1		1*	
P-17	1	1	1						
P-18	1	1	1		1*			1*	
P-19		1	1		1*				
P-20	1		1						

trainee left the hospital before returning the survey; parents and Patient 16 (P-16) did not have time to fill the survey before another appointment; and Patient 17 (P-17) who rejected the survey even though they were considered capable of filling it.

Yellow cells indicate surveys where only open-ended questions were used. Those cases are patients deemed not cognitively capable of undertaking the full questionnaire, and parents observing for a second time. A special case is Session 2 of Patient 18 (P-18), where the parent operated the robot. Due to several system errors and technical interventions caused by a software bug, the data from that questionnaire was not analysed.

5.2 Acceptance Questionnaire Results

This section reports on the Acceptance questionnaire results collected from all participants during Phase 2 in order to measure the acceptance of the SAR prototype delivering paediatric rehabilitation.

5.2.1 Reliability Analysis

The internal reliability analysis of the survey data collected has been calculated using Cronbach's alpha reliability measure as explained in Subsection 2.4.1.

Table 5.7 reports the Cronbach's alpha for each of the constructs of the physiotherapists' Acceptance questionnaire. Anxiety 2 (ANX2), measuring the extent to which participants felt scared of the robot, did not reach the 0.7 threshold required to pass the reliability test. Inspection of the responses for this construct showed universal *Disagreement/Strong Disagreement* across all physiotherapists, indicating no participants feared the robot. Attitude (ATT), Perceived Adaptability (PAD) and Social Influence (SI) are also constructs that did not meet the reliability threshold.

Table 5.7: Physiotherapists' Acceptance questionnaire Cronbach's alpha.

Construct	Cronbach's alpha
ANX1	0.83
ANX2	0.55
ATT	0.63
FC	0.86
ITU	0.88
PAD	0.4
PEOU	0.84
PU	0.79
SI	0.63
TR	0.79

The Cronbach's alpha for each of the constructs of the parents' Acceptance questionnaire is reported in Table 5.8.

Similarly to the physiotherapists' responses, the construct measuring the extent to which participants felt scared of the robot (ANX2) did not pass the reliability measure; however, it should be noted that all participants showed universal Disagreement/Strong Disagreement, indicating that none of the participants feared the robot. The construct Perceived Ease of Use (PEOU) obtained a Cronbach's alpha value of 0.68; however, if removing item *"I think I can use the robot when I have a good manual"* the measure

Table 5.8: Parents' Acceptance questionnaire Cronbach's alpha.

Construct	Cronbach's alpha
ANX1	0.61
ANX2	0.01
ATT	0.82
FC	0.67
PEOU	0.68
PU	0.67
TR	0.91

increases to 0.78. Similarly the Perceived Usefulness (PU) category, which obtained an alpha of 0.67, increased to 0.75 when removing the item *"It would be convenient to have the robot for therapy sessions together with the physiotherapist"*. Anxiety (ANX1), measuring to what extent parents were afraid of making mistakes or damaging the robot, and Facilitating Conditions (FC), did not meet the reliability threshold reaching 0.61 and 0.67 respectively.

The internal reliability measure of the patients' questionnaire is reported in Table 5.9. As with physiotherapists' and parent's questionnaire Anxiety 2 (ANX2), indicating the extent of fear or anxiety of the robot, did not pass the reliability test. Inspection of responses for this construct confirmed there was no variation in responses, with responses indicating no fear of the robot. The Social Presence (SP) in the patients' questionnaire also did not meet the reliability requirement, reaching 0.56.

Table 5.9: Patients' Acceptance Questionnaire Cronbach's alpha.

Construct	Cronbach's alpha
ANX2	0.69
ATT	0.89
PENJ	0.95
PS	0.81
PU	0.89
SP	0.56
TR	0.88

The Cronbach's alpha is an important measure to evaluate the internal consistency of a questionnaire. However, it has its limitations and it can lead to wrongly discarded items in a questionnaire [218]. The data collected in this study has a limited sample size (19 surveys from physiotherapists, 20 from parents, and 13 from patients) which affects the value of our alpha. Furthermore, constructs showing universal Disagreement/Strong Disagreement such as Anxiety 2 (ANX2), clearly indicating that participants were not scared of the robot, obtained lower scores in the internal reliability measure. For those reasons, the Cronbach's alpha results are reported for information purposes only, not for exclusion of the constructs. Instead of just providing the mean and the standard deviation for all the constructs, likert plots are presented to show all participants' responses in a more transparent form. The Acceptance questionnaire together with observations notes, and open ended survey responses will provide a clear picture of the acceptance of the robot when delivering rehabilitation.

5.2.2 Physiotherapists' Acceptance

Eight physiotherapists operated the robot to deliver rehabilitation sessions to different patients. This subsection reports the physiotherapists' Acceptance questionnaire results after their first session, and then how their responses tracked over multiple sessions.

Figure 5.2 shows Acceptance Questionnaire responses provided by 8 participating physiotherapists after their very first experience with the robot. Therapists' responses are grouped by category, with each row in the graph showing the percentage of responses for each category on the scale. Negative responses are represented on the left side of the graph, and positive on the right. Therefore, the Anxiety (ANX1 and ANX2) categories have been reversed to show positive responses (i.e, less perceived anxiety) on the right side of the figure. For completeness of the results, Table 5.10 provides the mean (μ) and the standard deviation (σ) for each of the constructs, which is the suggested way to report the results from the authors of the original questionnaire [85].

Table 5.10: Physiotherapists' Acceptance questionnaire mean and standard deviation after 1st session operating the robot (N=8).

Construct	Mean (μ)	Standard Deviation (σ)
Attitude (ATT)	4.38	0.50
Anxiety 2 reversed (R_ANX2)	4.63	0.50
Perceived Usefulness (PU)	4.21	0.59
Perceived Ease of Use (PEOU)	4.20	0.65
Social Influence (SI)	3.91	0.73
Facilitating Conditions (FC)	3.56	0.73
Perceived Adaptability (PAD)	3.22	0.95
Intention to Use (ITU)	3.54	0.72
Anxiety 1 reversed (R_ANX1)	3.13	1.15
Trust (TR)	2.88	0.89

Inspection of Figure 5.2 shows physiotherapists attitudes (ATT) towards using the SAR in rehabilitation sessions is universally positive. All therapists also indicated not being afraid or scared of the robot (R_ANX2) reaching 100% of positive responses. Therapists

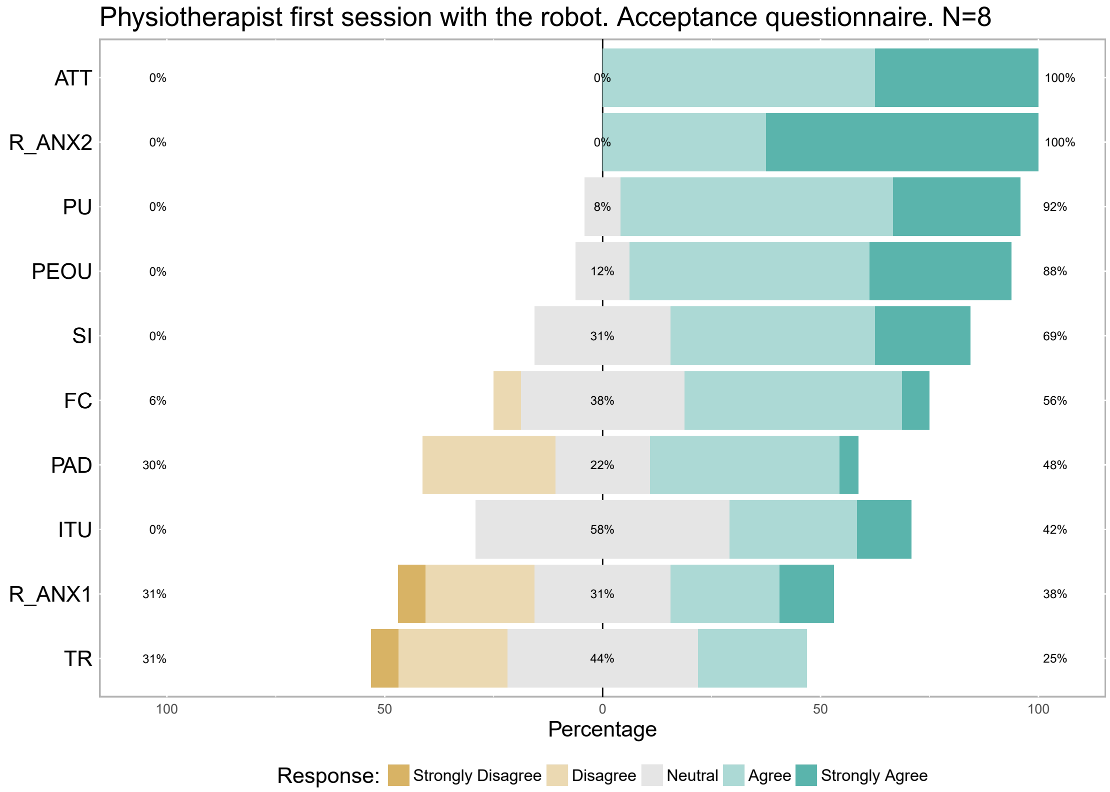


Figure 5.2: Physiotherapists' Acceptance questionnaire results after 1st session operating the robot (N=8). Attitude (ATT), Anxiety 2 reversed (R_ANX2), Perceived Usefulness (PU), Perceived Ease of Use (PEOU), Social Influence (SI), Facilitating Conditions (FC), Perceived Adaptability (PAD), Intention to Use (ITU), Anxiety 1 reversed (R_ANX1), no anxious on the right side, and Trust (TR).

overwhelmingly agreed that the SAR was useful in their sessions (PU) and easy to use (PEOU), with 92% and 88% of the responses indicating agreement to these assertions respectively after first use. On the Social Influence (SI) construct, physiotherapists generally agreed that parents and patients felt positive about their use of the robot in their rehabilitation sessions with 69% of positive responses. Facilitating Conditions (FC), examining the extent to which therapists felt equipped to use the SAR effectively, obtained 56% positive responses (*Agree/Strongly Agree*) from therapists delivering therapy. However, therapists were mostly neutral to questions of their Intention to Use (ITU) the SAR in future sessions. While no one disagreed, the most prominent response was neutral at 58%, while the remaining 42% either agreed or strongly agreed. Perceived Adaptability (PAD), Trust (TR) and Anxiety due to making mistakes or breaking the robot (R_ANX1) generated the most polarised responses. After first use of the SAR in therapy, around 31% of responses indicated the robot not being adaptable to the physiotherapists' needs in their rehabilitation sessions, some level of distrust, and anxiety; with a similar percentage indicating some level of adaptability, trust, and no anxiety.

Of particular interest was the evolution of therapist perceptions of the SAR after multiple uses. To this end, of the 8 therapists, 6 participated in a further two or more sessions with the robot, in which survey data continued to be collected. While all therapists were invited to continue, two therapists were unavailable for further participation during the trial period.

Figure 5.3 shows the physiotherapists' perceptions over multiple sessions, plotting the mean response to each category of questions after each session. Each graph represents a different construct in which physiotherapists' responses are calculated individually. *Strongly Disagree* responses are represented with 1, *Strongly Agree* responses with 5 on the ordinate axis. The number of the session in which the physiotherapists responded are represented on the horizontal axis.

Three of the six therapists participating over multiple sessions indicated reduced feelings of fear of making mistakes when using the robot (ANX1) after using the system 2 or more times (Figure 5.3a). Only one therapist (Physiotherapist F) indicated a substantial increase in anxiety after two sessions, while all others remained largely stable. Physiotherapists participating over multiple sessions always reported very low feelings of anxiety for being afraid or scared of the robot (ANX2) after using the system two or more times (Figure 5.3b). Only one therapist (Physiotherapist C) indicated an increase to neutral after their third session.

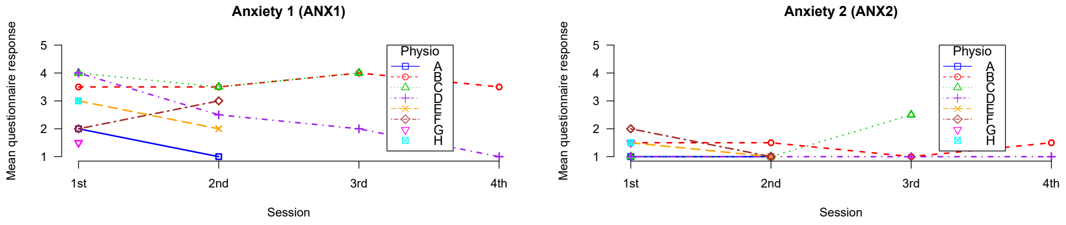
Figure 5.3c shows that the physiotherapists' attitude (ATT) to use the robot in rehabilitation is the most positive construct with responses between agreement and strong agreement over multiple sessions for all therapists.

After two sessions, all therapists agreed they felt equipped to use the robot effectively (Figure 5.3d). Four of the therapists responded with *Neutral* or *Agreement* to statements of their intention to use (ITU) the system in future sessions (Figure 5.3e), however, two therapists (Physiotherapists B and E) reported mostly *Neutral* or *Disagree* responses across their sessions (4 and 2 sessions respectively).

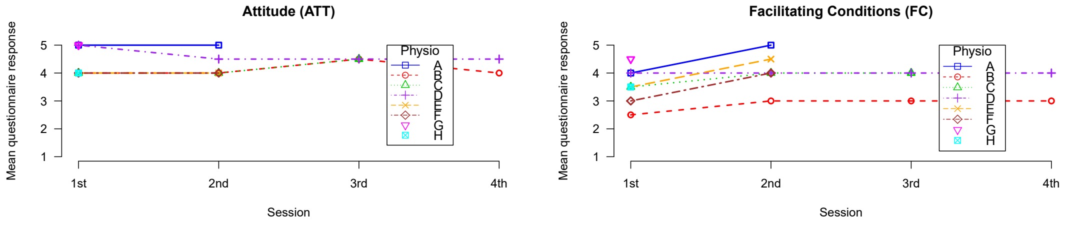
Most of the Perceived Adaptability responses are between Disagree and Neutral over multiple sessions, indicating physiotherapists who perceived the robot as not being adaptable enough to the needs of their rehabilitation sessions (Figure 5.3f). However, on the Social Influence (SI) construct, physiotherapists reported that parents and patients felt positive about the use of the robot in their rehabilitation sessions with most of the responses indicating agreement (Figure 5.3i).

Figure 5.3h shows that the physiotherapists' Perceived Usefulness (PU) of the robot shifts slightly to negative. However, it is still the most positive category with most of the responses above 3 (*Neutral*). A majority of responses to the system's Perceived Ease-Of-Use were *Agree/Strongly Agree*, with only one physiotherapist (Physiotherapist B) provid-

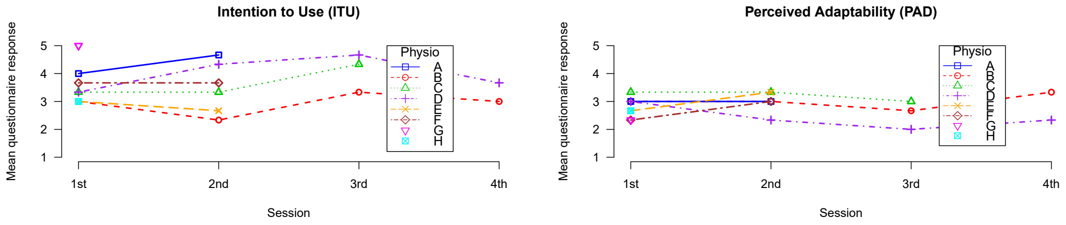
(a) Anxiety 1 **(b)** Anxiety 2



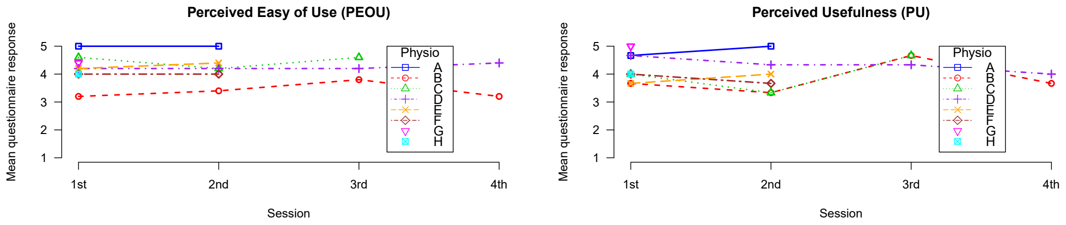
(c) Attitude **(d)** Facilitating Conditions



(e) Intention to Use **(f)** Perceived Adaptability



(g) Perceived Ease of Use **(h)** Perceived Usefulness



(i) Social Influence **(j)** Trust

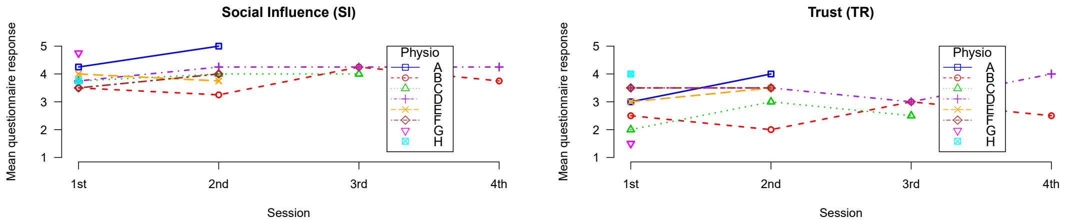


Figure 5.3: Acceptance questionnaire results per physiotherapists over time. Mean questionnaire response: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree.

ing a *Neutral* response after their fourth session (Figure 5.3g).

Results overall show Trust (TR) in the system slightly increases after using it multiple times, however most of the evaluations oscillate between between *Neutral* or *Disagreement*, suggesting some level of uncertainty, or perhaps reserved judgement (Figure 5.3j). This is explored later in open feedback response analysis.

5.2.3 Parents' Acceptance

Figure 5.4 shows Acceptance questionnaire results for parents observing a session, and Table 5.11 provides the mean (μ) and the standard deviation (σ) for each of the constructs.

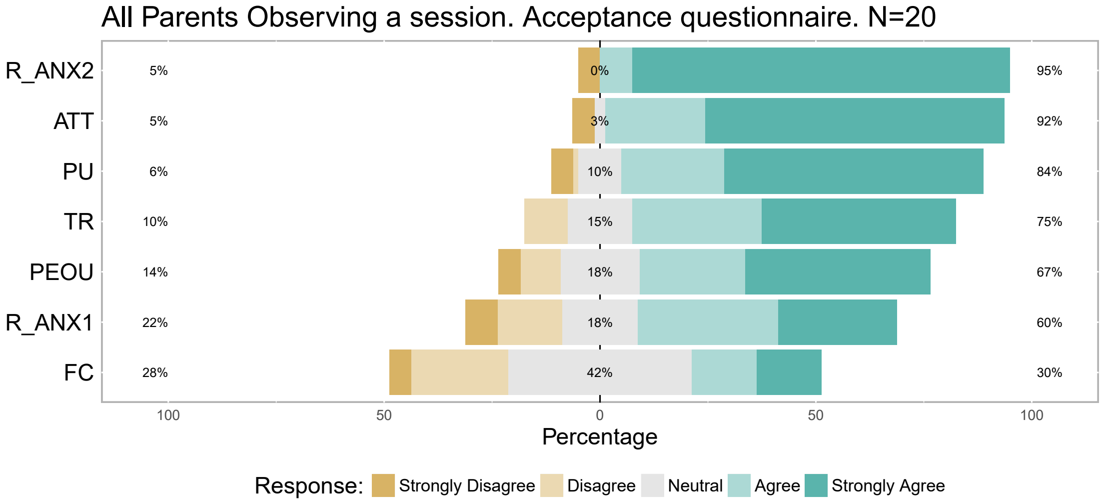


Figure 5.4: All Acceptance questionnaire results for parents (N=20) observing a session with the robot operated by a physiotherapist. Anxiety 2 reversed (R_ANX2) no anxious on the right side, Attitude (ATT), Perceived Usefulness (PU), Trust (TR), Perceived Ease of Use (PEOU), Anxiety 1 reversed (R_ANX1) no anxious on the right side, Facilitating Conditions (FC).

Table 5.11: All Acceptance questionnaire mean and standard deviation for parents (N=20) observing a session with the robot operated by a physiotherapist.

Construct	**Mean (μ)**	**Standard Deviation (σ)**
Anxiety 2 reversed (R_ANX2)	4.73	0.91
Attitude (ATT)	4.51	0.97
Perceived Usefulness (PU)	4.33	1.05
Trust (TR)	4.10	1.01
Perceived Ease of Use (PEOU)	3.91	1.20
Anxiety 1 reversed (R_ANX1)	3.58	1.26
Facilitating Conditions (FC)	3.13	1.09

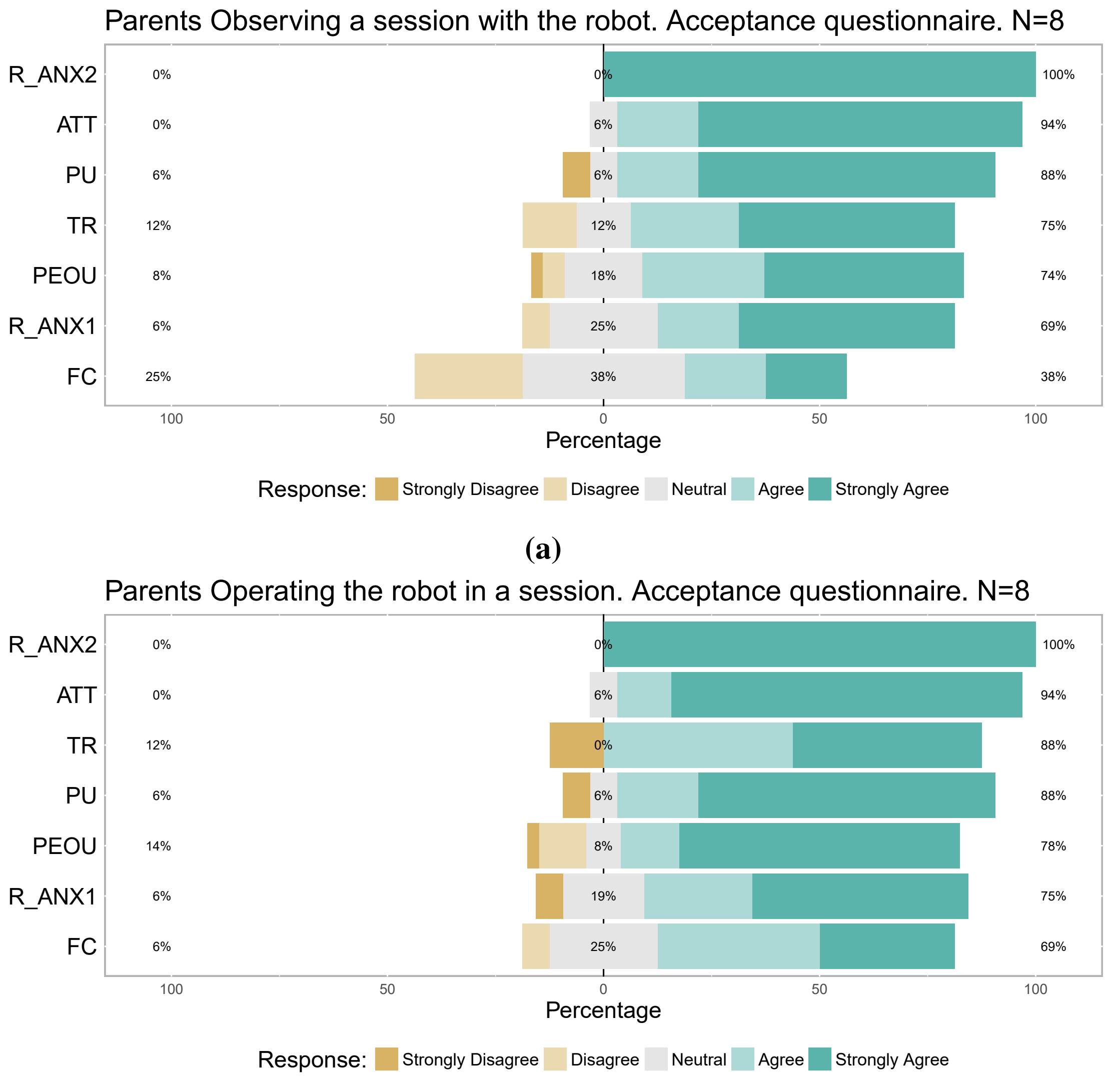
Table 5.12: Parents' Acceptance questionnaire mean and standard deviation comparing (a) Parents responses after observing-only, and (b) after then operating the robot in a subsequent session.

	Observing (N = 8)		**Operating** (N = 8)	
Construct	**Mean** (μ)	**SD** (σ)	**Mean** (μ)	**SD** (σ)
Anxiety 2 reversed (R_ANX2)	5.00	0.00	5.00	0.00
Attitude (ATT)	4.69	0.60	4.75	0.58
Perceived Usefulness (PU)	4.44	1.08	4.44	1.08
Trust (TR)	4.13	1.09	4.06	1.29
Perceived Ease of Use (PEOU)	4.10	1.05	4.27	1.17
Anxiety 1 reversed (R_ANX1)	4.13	1.02	4.13	1.15
Facilitating Conditions (FC)	3.31	1.08	3.94	0.93

After inspecting Figure 5.4 we can observe that parents overwhelmingly agree to not being afraid or scared of the robot (R_ANX2), reaching 95% of positive responses. Anxiety 2 (R_ANX2), Attitude (ATT) and Perceived Usefulness (PU) constructs ranked highest in terms of percentage of positive responses, with more than 80% of responses indicating agreement. Parents generally expressed trust (TR) in the SAR, with 75% positive responses, and overall perceived the robot as easy to use (PEOU) with 68% of positive responses. Feelings of anxiety related to making mistakes or breaking the robot (R_ANX1) was evident with 60% of responses agreeing with this sentiment. More diverse responses were obtained in questions of facilitating conditions (FC), with positive and negative responses getting similar percentages (i.e, 30% and 43%) neutral responses.

Results of the Acceptance questionnaire obtained from 20 parents observing a session are given in Figure 5.4. From those 20 parents, 8 participated in an additional session operating the SAR themselves. In order to compare how those 8 participants' perceptions changed in this new scenario, survey data from both observing and operating sessions is presented side by side in Figure 5.5, and Table 5.12 reports on the mean (μ) and the standard deviation (σ) for each of the constructs. Figure 5.5a shows those 8 particular parents' perceptions after observing a session delivered by a physiotherapist. Figure 5.5b presents parents' perceptions of the robot after their first time operating the robot (typically their second session exposed to the robot).

All the constructs increase or maintain the percentage of positive responses after operating the robot (Figure 5.5b). All parents reported not being afraid or scared of the robot (R_ANX2), reaching 100% of positive responses. Parent's attitude (ATT) towards the use of the robot in therapy maintains overwhelmingly positive responses (94%); and the Perceived Usefulness (PU) construct maintains its 88% of positive responses. The Trust (TR) construct exhibits polarisation in responses, with no neutral responses. Trust increments 13 percent in positive responses (75%) after operating the robot, while the initial 12% Dis-



(a)

(b)

Figure 5.5: Parents' Acceptance questionnaire results comparing (a) Parents responses (N=8) after observing-only, and (b) after then operating the robot in a subsequent session. Anxiety 2 reversed (R_ANX2), Attitude (ATT), Perceived Usefulness (PU), Trust (TR), Perceived Ease of Use (PEOU), Anxiety 1 reversed (R_ANX1), Facilitating Conditions (FC).

agree responses, appear to shift to Strongly Disagree. Perceived Ease of Use (PEOU) of the system increases 4 percent in positive (78%) and 6 percent in negative responses, while Anxiety category (fear of making mistakes or breaking the robot (R_ANX1)) increases 6 points in terms of positive responses. Facilitating Conditions (FC) is the construct with the biggest shift towards positive responses, reaching 69%, suggesting parents felt better prepared to make good use of the robot after operating it themselves.

5.2.4 Patients' Acceptance

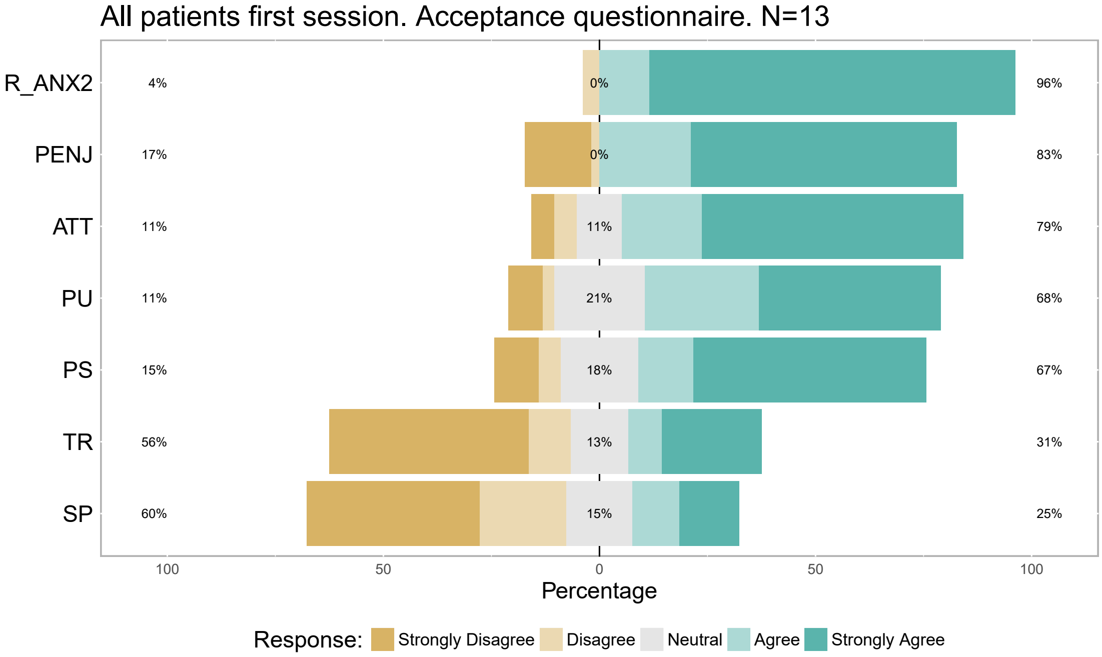


Figure 5.6: Acceptance questionnaire results for patients (N=13) after doing a session with the robot. Anxiety 2 reversed (R_ANX2), no anxious on the right side, Perceived Enjoyment (PENJ), Attitude (ATT), Perceived Usefulness (PU), Perceived Sociability (PS), Trust (TR), Social Presence (SP).

Table 5.13: Acceptance questionnaire mean and standard deviation for patients (N=13) after doing a session with the robot.

Construct	**Mean (μ)**	**Standard Deviation (σ)**
Anxiety 2 reversed (R_ANX2)	4.77	0.65
Perceived Enjoyment (PENJ)	4.12	1.45
Attitude (ATT)	4.24	1.17
Perceived Usefulness (PU)	3.92	1.22
Perceived Sociability (PS)	3.95	1.38
Trust (TR)	2.52	1.66
Social Presence (SP)	2.38	1.45

Figure 5.6 shows the patients' responses to the Acceptance Questionnaire grouped by construct, and Table 5.13 shows the mean and standard deviation for each of the constructs. Similarly to parents' results, patients were not scared or afraid of the robot. Anxiety 2 (R_ANX2) construct reached 96% of positive responses. Perceived Enjoyment (PENJ) also achieved a high positive response with 83% agreement, indicating that most of the patients enjoyed working with the robot. None of the responses to the perceived enjoy-

ment category were neutral, and almost all the negative responses (17%) were *Strongly Disagree* suggesting that patients had strong feelings about their enjoyment with the SAR. Patient Attitude (ATT) towards the robot ranked second in terms of positive responses (79%), with neutral and negative responses obtaining the same percentage (11%). More than two thirds of participant responses (68%) indicated that the robot was useful (PU) in their rehabilitation session, with a further 21% neutral. Similarly, more than two thirds of patient responses (67%) indicated patient perceived the robot as being friendly, nice, or understanding them (PS). A further 18% of the responses were neutral.

Trust (TR) and Social Presence (SP) were the constructs with a majority of responses disagreeing. More than half of the responses to the Trust construct were negative, obtaining 56% negative responses and 31% of positive responses. Most of the negative responses were *Strongly Disagree*. The construct that obtained the most negative responses was Social Presence (SP), with 60% of responses disagreeing to items such as the robot being like a real person, or the robot being a living creature.

5.2.5 Discussion

This study seeks to evaluate the level of acceptance of the proposed SAR prototype for paediatric rehabilitation in the context of clinical deployment in a busy children's hospital. Thus the focus is on the perceptions of all the participant groups: therapists, parents and patients. Therapists and parents hold primary duty of care for patients and have observed and/or used the SAR to deliver rehabilitation sessions. Patients are the primary beneficiaries of the SAR. Below the acceptance results obtained from each of these user groups is discussed.

Physiotherapist Acceptance

Perceived Usefulness (PU) provides the most direct measure of the SAR's effectiveness in the rehabilitation sessions it led. Physiotherapists rate the system's usefulness overwhelmingly positively, with several therapists noting observed improvements in exercises completed by patients known in general to be resistant. Physiotherapists' perceptions over multiple sessions with the robot does indicate a marginal drop in positive responses for Perceived Usefulness category (Figure 5.3h), with two physiotherapists (PT-B and C) downgrading their response to Neutral after the second session. Observation notes indicate both repeat sessions with these therapists involved negative patient emotions during the session. The SAR's lack of responsiveness to such events may have contributed to a reduction in Perceived Usefulness responses.

Physiotherapists report perceiving strong reinforcement from parents and patients to use the SAR in therapy sessions (Social Influence construct). This perception is maintained after multiple sessions of use. There exists the possibility that therapists may feel pressure to use the robot in order to please patients and parents. However, therapists also indicate that the SAR is both a good idea (ATT) and useful for rehabilitation (PU), suggesting undue pressure is not a concern of therapists.

The high rating of Perceived Ease of Use and its stability over time (Figure 5.2 and Figure 5.3g) provide compelling evidence for the system's successful integration with therapists' needs without the need for specific technical training. Therapists received only a 5 minute introduction to the system delivered by a physiotherapist team member. This modest level of training to operate the robot further supports the high positive responses to the system's perceived ease of use. While the brief introduction to the system appeared to be sufficient to make use of it, more formal training would likely provide participants more confidence when operating the robot, and may also help to mitigate system disruptions (discussed in Section 4.2).

The Facilitating Conditions (FC) category reflects a less conclusive result after the first session, with just under half the responses indicating some doubt as to whether therapists felt sufficiently equipped to use the SAR effectively. Encouragingly however, positive responses increase after the second use, suggesting successful experiences using the robot with patients reinforces therapists' confidence in making effective use of the aid. This concept that experience brings positive attitudes and confidence has been already explored previously with the use of computers [124].

Compared with the Perceived Ease of Use (PEOU) responses, therapists express less certainty on questions of their intention to make use of the system (ITU), though neutral responses remain at 58%, and 42% of positive responses. Responses over multiple sessions change without a clear pattern, indicating that the Intention to Use category of responses highly depends on the physiotherapists' most recent experience with the robot. For instance, the second session of physiotherapist B in Figure 5.3e corresponds to a patient that even after participating well in the session, did not like the robot and preferred to not do another session again. The high proportion of neutral responses might also reflect the inability of therapists to pre-configure the SAR for their patients' sessions without technician support. Even though during this study the robot was available in the hospital, physiotherapists were able to use the robot only when the research engineer visited the hospital (once per week approximately) and configured the session parameters into the system. This issue, as discussed in Chapter 4, motivated the development of tablet-based interface for clinicians to allow therapists to configure sessions, offering all the required parameters: patient's name, carer's name, exercises, number of sets, repetitions, and entertainment modules. The tablet-based interface became available at the end of Phase 2, thus, the physiotherapists' perceptions after the introduction of the tablet interface were not tested.

Physiotherapists' responses to the Perceived Adaptability (PAD) category were mostly neutral, and did not improve over multiple sessions. Researcher observation notes indicate that those results are most likely reflecting the robot's lack of flexibility to allow physiotherapists to alter the order of the exercises in the session, or the robot's lack of responsiveness to the current patient's mood. For instance, the robot was unable to react to a patient that expressed dislike of the robot. However, it appears clear that these expressed deficits do not significantly affect therapist perceptions of the system's usefulness (PU) or attitude (ATT). It is possible, however, that these deficits may have greater impact over longer and/or more frequent sessions. For example, in a different context with children, Kanda et al. [104] reported that the social behaviour of a robot encouraged children to work, but it lasted no more than 2 lessons.

Unsurprisingly, therapist responses to questions of trust are most polarised. Arguably the survey questions on this topic do not properly capture the most relevant interpretation of trust for this application: that therapists trust the robot to deliver the correct advice to patients. However, the questions do capture broader perceptions of the SAR's design as a care delivery system. Encouragingly, results in Figure 5.3j suggest trust in the SAR's instruction improved over multiple sessions using it, suggesting other more positively ranked features such as Perceived Usefulness (PU), are also positively influencing trust over time.

As with trust, Anxiety 1 (R_ANX1) with respect to possible breakage or operation failures reflects mixed views. Most negative responses from physiotherapists were to the question 'I would be afraid to break something when using the robot', suggesting therapists saw the robot as expensive and fragile. Multiple use of the system sees a reduction in this anxiety, suggesting experience assists in allaying these concerns. Levels of anxiety (R_ANX2) with respect to being afraid or scared of the robot are very low, and in general diminish over multiple uses. Only one therapist (Physiotherapist C) indicated an increase to neutral after their third session. Session observations indicated that the robot malfunctioned when standing up, and this was the likely cause of this shift. This, however, highlights the importance of the system's reliability to therapist's anxiety with the SAR.

Parent Acceptance

Overall, parents who operated the robot generally provided more positive responses after observing a session than those who only observed the robot. Parent survey responses reflect similar levels of Perceived Usefulness to those obtained from physiotherapists. Parents indicate near universal agreement that the SAR is useful in their child's rehabilitation sessions after both observing and operating the SAR themselves. Perceived usefulness of the robot was maintained after operating it without a physiotherapist in the room. Positive responses to questions of attitude towards use of the SAR (ATT) suggest parents overwhelmingly like the robot itself, and its role in rehabilitation.

Parents also reflect a similar level of enthusiasm as therapists for including the SAR in rehabilitation (ATT), however, in general do not perceive the robot as being as easy to use as therapists, presumably because they did not actually use it. However, parents who operated the robot (N=8) in their second session perceived the robot as more easy to use than parents who only observed (N=20). Operating parents still rate 10% less in terms of positive responses (Figure 5.5b) compared with therapists after a single use of the SAR (Figure 5.2). Parents observed a session first and then received the same 5 minute training as physiotherapists. This result might indicate that parents, who are not experts in physiotherapy, need more training and/or a different kind of training than physiotherapists to make effective use of the robot. Generally, physiotherapists may be more comfortable with technology as part of their work than parents.

Facilitating Conditions (FC) has the highest increase in terms of positive responses for parents who operated the robot themselves. It reaches a higher percentage in terms of positive responses than physiotherapists responses after a single use of the robot. As with physiotherapists' Facilitating Conditions results, operating experience with the system appears to promote confidence in both the SAR's operation, and parents' ability to make use of it effectively for their child's rehabilitation.

Parents report a higher level of trust (TR) in the SAR compared with therapists, both after observation and after operating the robot. This is not surprising given parents do not hold the same degree of clinical responsibility as therapists. Moreover, the SAR is introduced to parents in a hospital environment, by a therapist. It is therefore likely that parents infer a level of trust in the system from the therapist's (and hospital's) judgement to offer the SAR in their child's care delivery.

Parent anxiety associated with making mistakes or breaking the robot (R_ANX1) appears to be lower than the physiotherapists which is somewhat surprising given parents expressed less confidence using the robot effectively. A possible explanation could be related again to differences in the level of responsibility between parents and therapists. Therapists, as employees in the hospital, might feel more responsibility about the assets than parents. Parents' anxiety results improve after operating the robot, suggesting again that experience assists in reducing their concerns of damaging the system or making mistakes. Similarly to the physiotherapists' survey responses, parents' responses to questions such as being afraid or scared of the robot (R_ANX2) are overwhelmingly positive, indicating parents were not afraid of the robot.

Patient Acceptance

From the 20 patients who participated, a relatively limited number of surveys were obtained (13) due to the young age or medical condition of some of the patients.

Patients, in general, liked the idea of having the robot in their rehabilitation sessions (ATT), and indicated that the robot was useful (PU) for them. Patient responses to questions in the Attitude (ATT) and Perceived Usefulness (PU) category were most positive, though slightly less positive than parents reaching 79% and 68% positive responses respectively. The Perceived Sociability (PS) of the robot, asking if patients perceived the robot as friendly, nice or understanding them, also featured as highly positive.

Most of the patients' responses (83%) indicated that they enjoyed doing the rehabilitation exercises with the robot (PENJ). Session observation data shows patients overwhelmingly expressed enjoyment during sessions with the robot, and this was maintained over multiple sessions.

The robot's lack of responsiveness, or the robot not being able to hold a conversation appeared to impact the Social Presence (SP) construct. This construct gets most of the negative responses (60%), clearly reflecting a perceived lack of authentic social presence in the SAR prototype. This replicates the findings of Heerink et al. [86] who noted that a lack of social abilities can negatively impact Social Presence (SP) construct, which in turn may impact the participants' perceived enjoyment (PENJ).

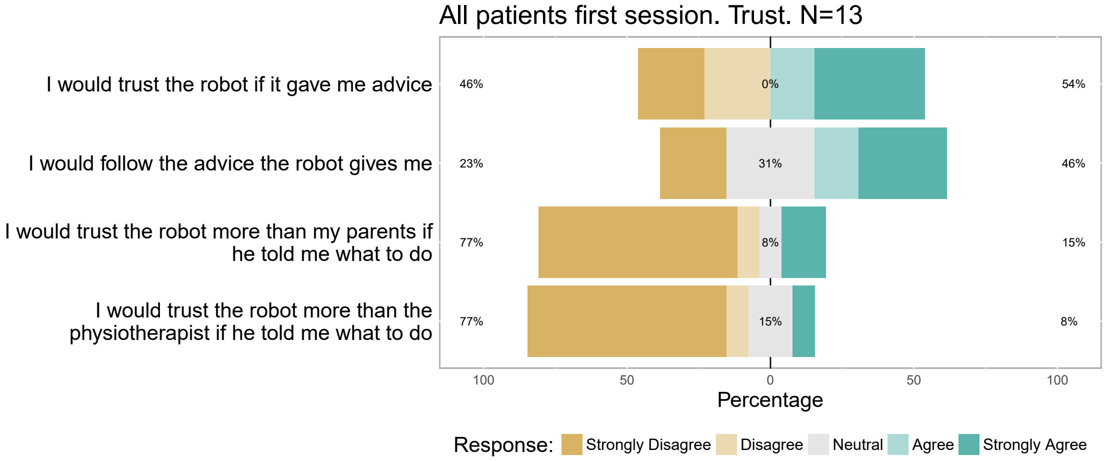


Figure 5.7: Patients' responses for Trust questions (N=13).

Notably, patients' responses to the question of trust exhibited more negative responses than physiotherapists. Figure 5.7 shows the patients' trust responses for individual questions within the construct. Questions comparing if they would trust the robot more than their parents or their physiotherapist obtained 77% negative responses, with most strongly disagreeing. However, trust questions that are common to all participants such as "I would trust the robot if it gave me advice" and "I would follow the advice the robot gives me" reach approximately 50% positive responses. If comparing the trust items that are common to all participants, patients trusted the robot more than physiotherapists but trusted it less than parents. Given one of the trust questions directly referenced trusting the robot's advice more than their parent's, this result is not necessarily surprising. Patients, similarly to parents and therapists, overwhelmingly reported not being afraid or scared of the robot (R_ANX2).

5.3 Godspeed Questionnaire Results

The Godspeed questionnaire provides additional metrics to the Acceptance questionnaire of participants' perceptions of the robot. Godspeed questionnaire data were collected from all participant groups. All categories of the questionnaire passed the Cronbach's alpha reliability measure [218]. Table 5.14 reports the Cronbach's alpha for each of the constructs of the participants' questionnaire.

Table 5.14: Participants' Godspeed questionnaire Cronbach's alpha.

Construct	**Cronbach's alpha**
Anthropomorphism (ANTH)	0.80
Animacy (ANIM)	0.76
Likeability (LIKE)	0.89
Perceived Intelligence (PeIn)	0.85
Perceived Safety (PeSa)	0.73

5.3.1 Physiotherapists' Godspeed Questionnaire

Questionnaires were completed after first use of the system by physiotherapists, and over multiple sessions. Physiotherapists' responses to the questionnaire after first use of the SAR are grouped per category (Figure 5.8). Each row shows the percentage of responses for each category on a scale. The lowest score of 1 to 5 is 1 indicating for example that the SAR is not anthropomorphic at all, while 5 would indicate the SAR as being very anthropomorphic. Table 5.15 reports means and standard deviation responses for each of the construct.

After first use of the SAR (Figure 5.8), almost all physiotherapists perceived the robot as being very intelligent (PeIn) and likeable (LIKE), reaching 85% and 90% of responses respectively. Half of the responses considered the robot being animated, and one third neutral. Perceived Safety (PeSa) responses are mostly divided between very safe and

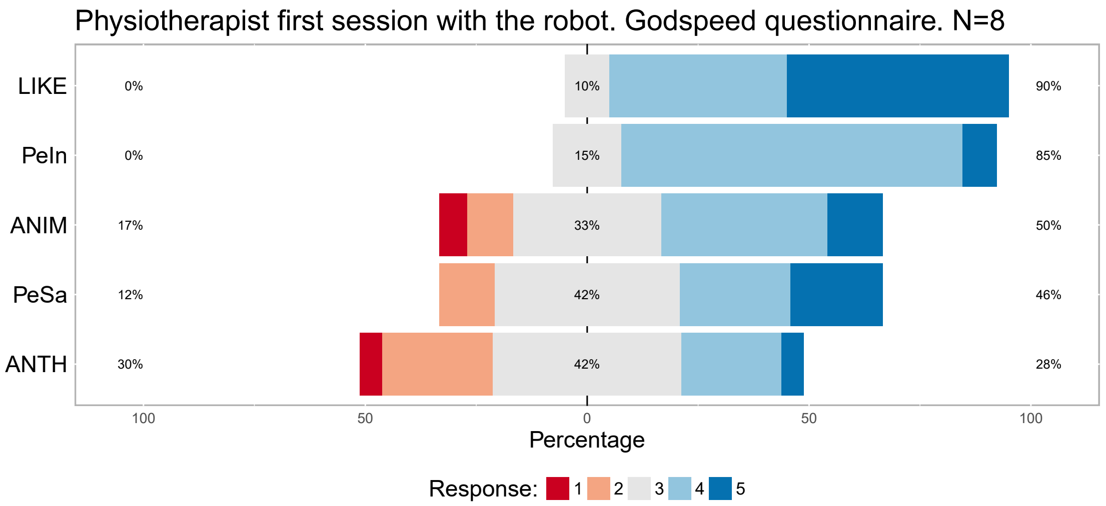


Figure 5.8: Physiotherapists' Godspeed questionnaire results after 1st session operating the robot (N=8). Likeability (LIKE), Perceived Intelligence (PeIn), Animacy (ANIM), Perceived Safety (PeSa), Anthropomorphism (ANTH).

Table 5.15: Physiotherapists' Godspeed questionnaire mean and standard deviation after 1st session operating the robot (N=8).

Construct	**Mean** (μ)	**Standard Deviation** (σ)
Likeability (LIKE)	4.40	0.67
Perceived Intelligence (PeIn)	3.92	0.48
Animacy (ANIM)	3.40	1.05
Perceived Safety (PeSa)	3.54	0.98
Anthropomorphism (ANTH)	2.98	0.95

somewhat safe responses, with just 12% of responses indicating not very safe. The Anthropomorphic (ANTH) category of the SAR obtains mostly neutral responses (somewhat anthropomorphic) with 42%, and 30% considering the robot not anthropomorphic.

Figure 5.9 shows the physiotherapists' responses over time, with each plot representing a survey construct. On the abscissa axis the session number in which the physiotherapist participated, on the ordinate axis the mean of the questionnaire response for the associated construct.

When inspecting Figure 5.9a, it can be observed that the perceived level of Anthropomorphism (ANTH) of the SAR slightly diminishes over sessions for 4 of the 8 therapists while generally holds steady for the others. Results tend to be polarised between not anthropomorphic and anthropomorphic. Similar responses were obtained for the Animacy (ANIM) category (Figure 5.9b), however, responses are more neutral if comparing with the Anthropomorphism category, indicating the robot was somewhat animated. The Likeability (LIKE) category (Figure 5.9c) has overwhelmingly positive responses. Phys-

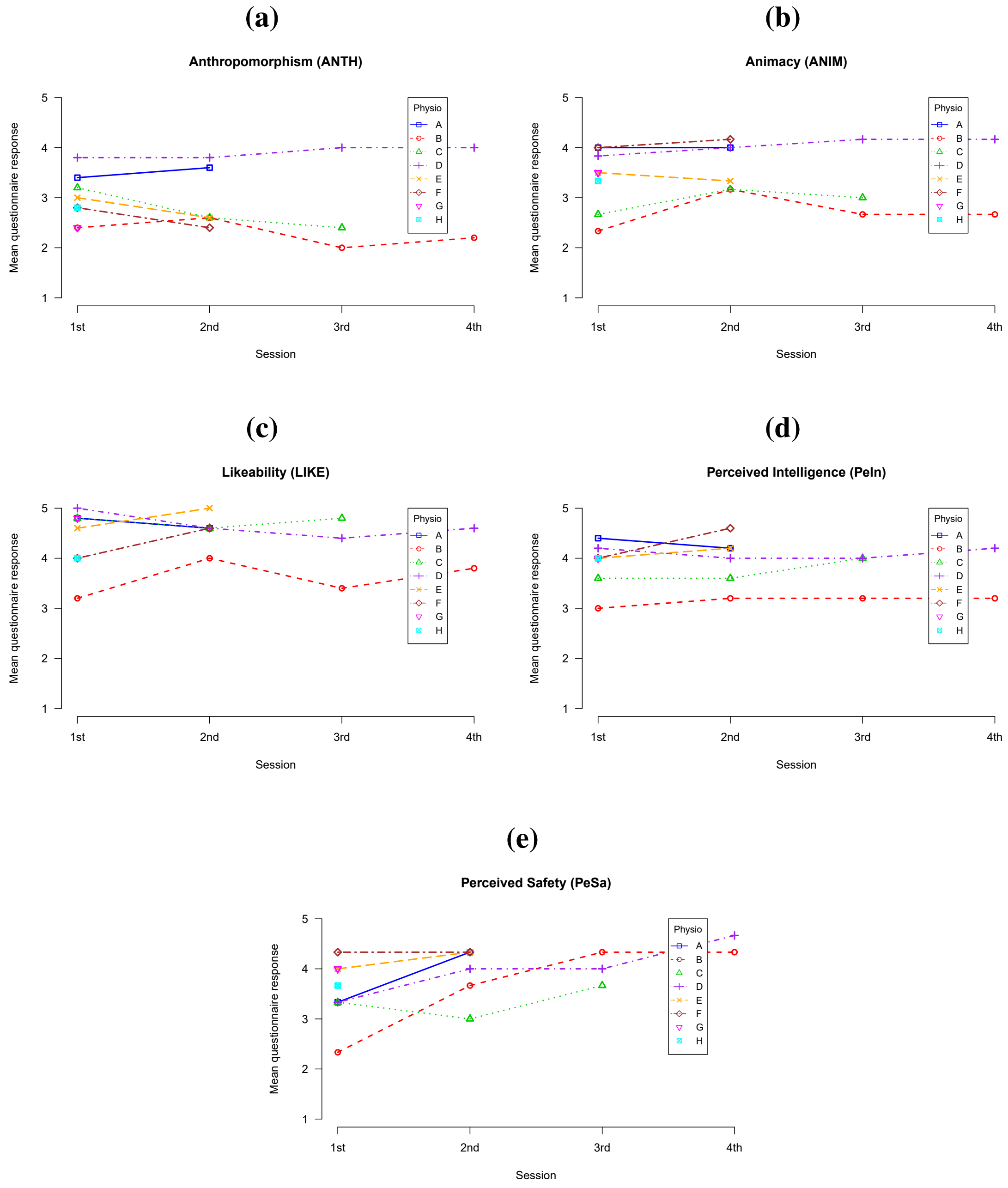


Figure 5.9: Godspeed questionnaire results per physiotherapists over time. (a) Anthropomorphism (ANTH), (b) Animacy (ANIM), (c) Likeability (LIKE), (d) Perceived Intelligence (PeIn), (e) Perceived Safety (PeSa).

iotherapists' responses over time indicate maintenance of high likeability, except for Physiotherapist B whose responses are between somewhat likeable and likeable. Perceived Intelligence (PeIn) is the most stable category over time. Most of the responses indicate the robot being intelligent, except for Physiotherapist B whose responses indicate the robot being somewhat intelligent (Figure 5.9d). The category that shows the most increase is the Perceived Safety category (PeSa) in Figure 5.9e, with almost all the responses increasing over multiple sessions, indicating more experience with the robot generated a higher perception of safety.

5.3.2 Parents' Godspeed Questionnaire

Figure 5.10 shows the results obtained from 20 parents after observing a single session for the first time being delivered by a physiotherapist operating the SAR. Table 5.16 reports the mean and standard deviation for each of the constructs.

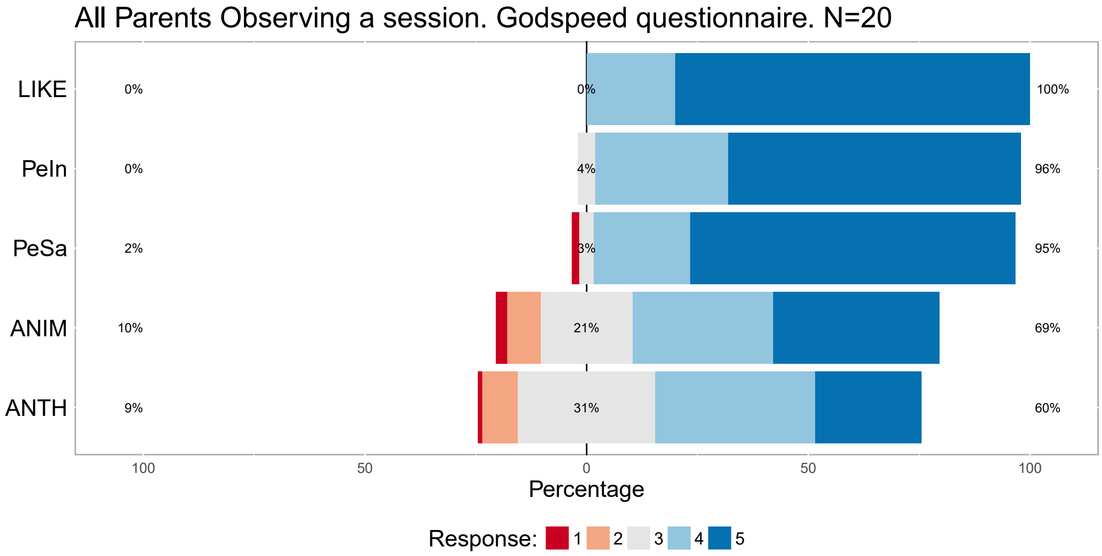


Figure 5.10: All Godspeed questionnaire results for parents (N=20) observing a session with the robot operated by a physiotherapist. Likeability (LIKE), Perceived Intelligence (PeIn), Perceived Safety (PeSa), Animacy (ANIM), Anthropomorphism (ANTH).

Considering Figure 5.10, all parents overwhelmingly liked (LIKE) the robot after observing a session delivered by a physiotherapist. Parents also perceived the robot as being very intelligent (PeIn) and very safe (PeSa), reaching 96% and 95% of responses respectively. Parents, however, rated the robot being animated (ANIM) and anthropomorphic (ANTH) in 69% and 60% of the responses respectively, and with 21% and 32% of neutral responses respectively.

Table 5.16: All Godspeed questionnaire mean and standard deviation for parents (N=20) observing a session with the robot operated by a physiotherapist.

Construct	**Mean (μ)**	**Standard Deviation (σ)**
Likeability (LIKE)	4.80	0.40
Perceived Intelligence (PeIn)	4.62	0.56
Perceived Safety (PeSa)	4.65	0.71
Animacy (ANIM)	3.94	1.06
Anthropomorphism (ANTH)	3.74	0.95

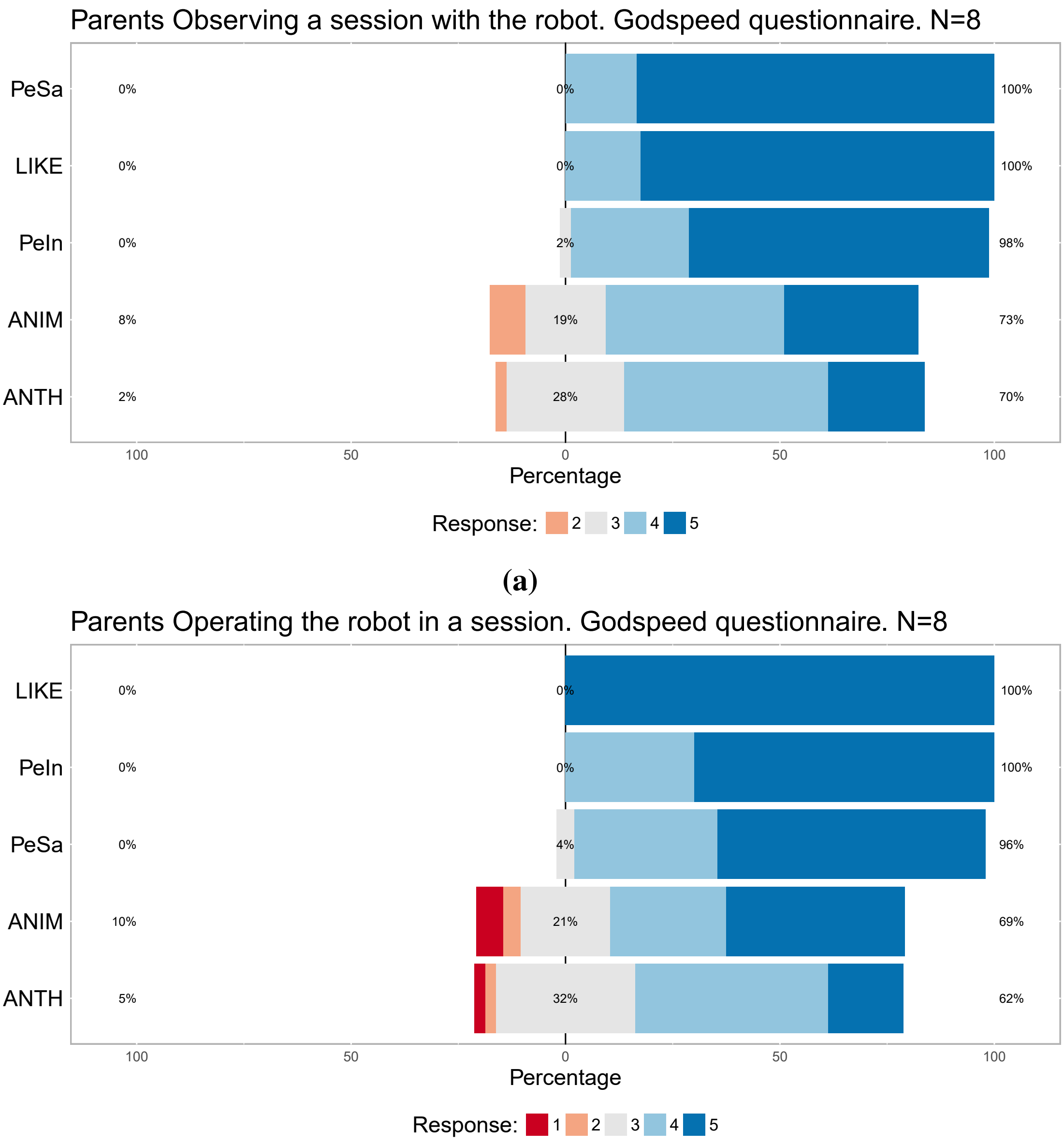
Table 5.17: Parents' Godspeed questionnaire mean and standard deviation comparing (a) Parents responses after observing-only, and (b) after then operating the robot in a subsequent session.

	Observing (N = 8)		**Operating** (N = 8)	
Construct	**Mean (μ)**	**SD (σ)**	**Mean (μ)**	**SD (σ)**
Perceived Safety (PeSa)	4.83	0.38	4.58	0.58
Likeability (LIKE)	4.83	0.38	5.00	0.00
Perceived Intelligence (PeIn)	4.68	0.53	4.70	0.46
Animacy (ANIM)	3.96	0.92	3.94	1.17
Anthropomorphism (ANTH)	3.90	0.78	3.73	0.88

Of the 20 recruited parents, 8 participated and operated the robot themselves in a further rehabilitation session. In order to compare how responses differ for those 8 parent's after observing a session, and a subsequent session operating the robot, results are plotted in Figure 5.11 showing responses after observing (5.11a) and operating (5.11b) from the same eight parents. Table 5.17 reports the mean and standard deviation for each of the constructs.

Godspeed survey responses for parents who operated the robot during therapy in subsequent sessions (Figure 5.11a) were slightly positive (between 2% and 10%) in all categories (except for Likeability category which obtained 100% of positive responses) when comparing to all parent responses together (Figure 5.10).

From Figure 5.11b it can be seen that Likeability (LIKE), Perceived Intelligence (PeIn), and Perceived Safety (PeSa) categories maintained close to 100% positive responses, indicating the robot was very likeable, and perceived to be very intelligent and safe after operating it. Animacy (ANIM) registered a modest decline, indicating that the robot was life-like with 69% of the responses, but conversely, 10% of responses also reported the robot not being animated. Anthropomorphism (ANTH) registered the greatest shift after operating the robot when compared with only observing, decreasing 8 percent from positive to neutral or to negative responses.



(a)

(b)

Figure 5.11: Godspeed questionnaire results comparing (a) Parents responses (N=8) after observing-only, and (b) after then operating the robot in a subsequent session. Likeability (LIKE), Perceived Intelligence (PeIn), Perceived Safety (PeSa), Animacy (ANIM), Anthropomorphism (ANTH).

5.3.3 Patients' Godspeed Questionnaire

Patient responses to the Godspeed questionnaire are plotted in Figure 5.12. From Figure 5.12 it can be seen that responses to the robot's Likeability (LIKE) were most positive, with 86% of responses indicating they liked the robot. Perceived Intelligence (PeIn) ranked second, reaching 77% responses. Patients' questionnaire responses indicated that they perceived the robot as safe (PeSa), 74% of the responses were positive and 18% were negative.

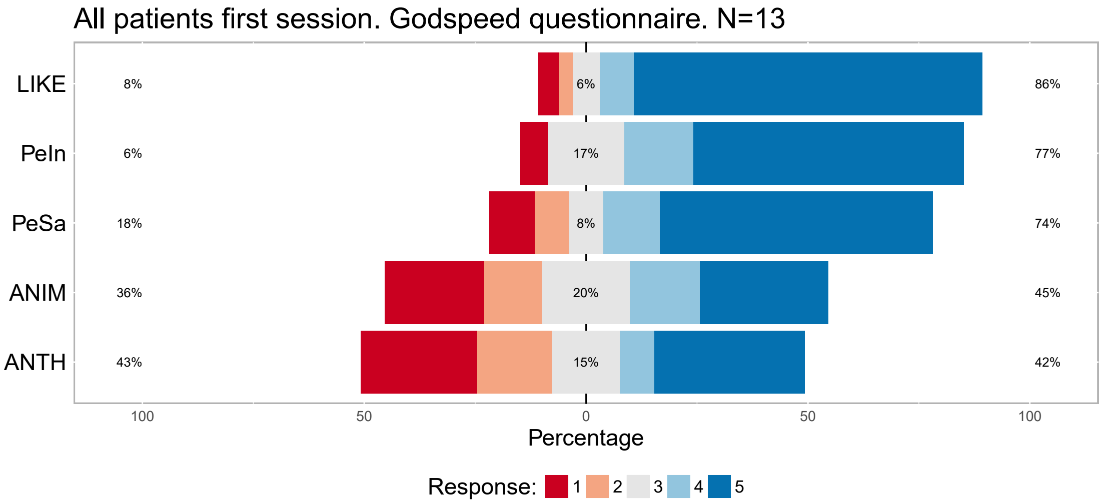


Figure 5.12: Godspeed questionnaire results for patients (N=13) after doing a session with the robot. Likeability (LIKE), Perceived Intelligence (PeIn), Perceived Safety (PeSa), Animacy (ANIM), Anthropomorphism (ANTH).

Table 5.18: Godspeed questionnaire mean and standard deviation for patients (N=13) after doing a session with the robot.

Construct	Mean (μ)	Standard Deviation (σ)
Likeability (LIKE)	4.52	1.06
Perceived Intelligence (PeIn)	4.25	1.14
Perceived Safety (PeSa)	4.08	1.40
Animacy (ANIM)	3.16	1.53
Anthropomorphism (ANTH)	3.06	1.64

Animacy (ANIM) and Anthropomorphism (ANTH) are the two categories with more polarised responses. Patients rated the robot as being animated with 45% of the responses, and not animated with 36%. Similarly, patients perceived the robot as being anthropomorphic with 42% of the responses, and not anthropomorphic with 43% of the responses, indicating patients were most divided about the robot's human likeness. Table 5.18 reports the mean and standard deviation for each of the constructs.

5.3.4 Discussion

Likeability achieves the strongest positive responses from the Godspeed survey for all groups. It should be noted that ambiguities in this measure have been highlighted previously [243]. Specifically, does likeability relate to the robot itself or the context of the task it is performing? Positive responses to questions of attitude towards use of the SAR (ATT) and Perceived Usefulness (PU) from the Acceptance Questionnaire, suggest participants overwhelmingly like the robot itself, as well as its role in rehabilitation.

Perceived Intelligence (PeIn) results offer the most interesting insights from the Godspeed Questionnaire. Therapists, parents, and patients rate the Perceived Intelligence of the robot highly (Figure 5.8, Figure 5.10, and Figure 5.12) despite the deliberately conservative approach to built-in artificial intelligence adopted in the SAR prototype's design. The strategy to constrain interactive capabilities by using only basic speech recognition and tactile inputs reduced reliance on error-prone natural language processing [106], which can be disruptive even when alternative modalities of input are provided. In line with Kim et al. [111], the perceived intelligence of the prototype SAR appears to reflect its ability to deliver care competently rather than its ability to comprehend, respond and interact intelligently in general. The Perceived Intelligence results seem to support the SAR's ability to convincingly play the earlier defined roles of being a demonstrator and coach for rehabilitation (explained in Section 3.1.7).

In contrast to Perceived Intelligence, Animacy (ANIM) was rated more negatively by all participant groups, most likely reflecting the system's lack of built-in responsiveness to events and patient emotion, observed repetitive speech delivery, and its lack of ability to hold a conversation. For example, when exercising the right leg after completing the left, the SAR uttered *'If it's too hard to hold your leg up, get someone to help you!'* to which a patient in one session responded *'You said that twice!'*. Longer robot sentences were perceived to be more repetitive. Patients indicated similar issues in the Social Presence (SP) construct from the Acceptance questionnaire. The Social Presence category obtained the lowest number in positive responses. The literature reports that a more socially communicative robot is more likely to be accepted [84], which is still an issue to be addressed in the robotic system. Therapists also reported similar issues in the Perceived Adaptability (PAD) construct from the Acceptance questionnaire. The Perceived Adaptability construct, which asked questions related to the robot being adaptable to their needs, obtained almost 50% positive responses, clearly indicating the robot not being as adaptable as desired by therapists.

The Perceived Safety (PeSa) category, measuring the level of danger perceived by the participants when in the presence of the SAR [8] obtained only 46% of positive responses from physiotherapists (Figure 5.8), and 74% of positive responses from patients (Figure 5.12). Even though physiotherapists' safety perceptions improve over multiple sessions (Figure 5.9e), their first session responses exhibited some conflict with their Anxiety 2 category (ANX2) responses of the Acceptance questionnaire, measuring the extent to which participants felt afraid of the robot. The Anxiety 2 construct (ANX2) in the Acceptance Questionnaire asked participants to rate in likert scale the following items:

- I find the robot intimidating.

- I find the robot scary.

Conversely, the Perceived Safety (PeSa) construct from the Godspeed Questionnaire includes the following differential scale items for participants to respond to:

- Anxious - Relaxed.
- Agitated - Calm.
- Quiescent - Surprised.

While both constructs try to measure the same concept, the ANX2 construct asks clearly if the participant feels intimidated or scared of the robot, whereas the Perceived Safety category does not provide any context. Thus, participants might have responded considering other concepts such as being anxious because they perceived the robot being expensive and fragile. Furthermore, it has been previously reported in the literature that Quiescent and Calm, which are synonyms used in the PeSa construct, are both in opposite positions of the scale [196] and those items might enter in conflict. Overall, it appears that the participants have not perceived being in danger when interacting with the robot, but do feel some anxiety when operating it. Qualitative feedback sheds further light on this issue which will be discussed in Section 5.4.

Parents are the participants who most perceived the robot being human-like or anthropomorphic (ANTH). Physiotherapists, with their extended background in correct human body movement, rate the robot relatively harshly on this measure. This was also evident in the early stages of design (Phase 1), during which therapists strongly advised excluding walking-based exercises due to the robot's incorrect gait. A human-likeness study using the NAO robot reported that having participants imitate the robot for a few minutes affected positively the human-likeness evaluation [151]. However, this contradicts the results presented here. Patients, the participants who imitated the robot, perceived the robot less anthropomorphic if comparing to physiotherapist or parent results. A meta analysis of the Godspeed questionnaire [243] reported that it is still not clear how the task context or the robot movements affect the anthropomorphic (ANTH) category in studies with the NAO robot. In this study, we could not determine the cause of the 8 percent drop in the Anthropomorphic category from positive to neutral or to negative responses of parents after operating the robot.

5.4 Open Ended Questionnaire Results

A general qualitative analysis was done with all the open ended responses provided by the participants. The responses were read multiple times in order to become familiar with the data, and to extract common patterns and themes. Some of the questions have had enough responses in order to extract themes [17]. Where a thematic analysis approach was not possible, common patterns in those questions have been extracted.

5.4.1 Physiotherapists' Open Ended Responses

Nineteen surveys were collected from physiotherapists. Surveys were collected after each physiotherapist's session with a new patient. The results of the general qualitative analysis are presented in Table 5.19. If a therapist mentioned the same answer but with a different patient, each of the answers was counted. The table shows themes or patterns extracted from the open ended questions. It indicates for each question (Q. No), the pattern or themes found (Pattern), the number of occurrences for each theme (Occ.), and an example.

To the first question **What do you think is missing in the robot to be a useful and legitimate aid?**, ten out of 19 surveys had a response. Nine responses noted Flexibility/Adaptability. Physiotherapists asked specifically for the robot to be better able to adapt to the present scenario or patient condition, allowing therapists to alter the exercise order or to divert from the set programme. Examples of these responses are: *"Flexibility - able to adapt to the presenting scenario (PT-B)"*; *"Choice of exercises (i.e. patient gets to choose what they want to do/the order) (PT-F)"*; *"Adaptability during sessions, e.g. change walk to sitting if the child cannot walk (PT-B)"*; *"Ability to adjust program to suit the situation at the time (PT-E)"*. Five surveys also mentioned Monitor/Feedback, such as the robot being able to evaluate the patient's performance and provide feedback accordingly. For example: *"Ability to monitor patient's quality with performance of exercises (PT-C)"*.

Therapists were also asked to list **the role of the robot that has attracted them the most**. Fourteen out of 19 surveys provided a response to this question. Demonstrator is the most mentioned role, appearing in 12 survey responses. Therapists commented that patients can visualise the correct performance of the exercises with clear verbal instructions from the SAR. For instance: *"Demonstration - allows patients to visually see the exercises/tasks required (PT-B)"*; *"Demonstration - good teaching tool in paediatric population (PT-D)"*. The *Motivator* role was mentioned in 10 surveys, reporting that the robot provides some fun, and visibly increases the patient compliance and participation. A physiotherapist explained in her response that most of the physiotherapist's work in the hospital *"is keeping child interested/motivated (PT-E)"*. Another therapist's support of motivation stated the SAR provided *"another tool to increase compliance in paediatric population (PT-C)"*. The *Companion* role was mentioned twice, with respondees noting that the SAR joining in each exercise *"keeps them [patient] at a good pace (PT-H)"* when doing the exercises.

Table 5.19: Physiotherapists' open ended responses. Number of the question (Q. No); the pattern found; the number of occurrences for that pattern (Occ.); and an example.

Q. No	Pattern	Occ.	Example
1	Flexibility/Adaptability	9	"Flexibility - able to adapt to the present scenario"
	Monitor/Feedback	5	"Ability to monitor patient's quality with performance of exercises"
2	Demonstration	12	"Demonstration - allows patients to visually see the exercises/tasks required"
	Motivator	10	"Motivator - much of physio here is keeping the child interested/motivated"
	Companion	2	"Keeps them at a good pace"
3	Technical failures	4	"Would be good if the robot could recover from falls or other mishaps independently"
	Flexibility/Adaptability	3	"Adaptability of the robot to the current situation"
	System Improvements	3	"Motivation. It currently has a good motivation, but there is a lot of repetition & patients might become frustrated with this"
4	Positive	14	"Enjoyed session, maximal participation"
	Comparing sessions	3	"He did the exercises better than he did previously, however he became distracted throughout"
	Negative	3	"Very poor compliance. [The robot] escalated patient's behaviour issues"
	Fatigue	2	"[The patient] was very fatigued, not as interested as usually is"
5	Enjoyable session	4	"It was a great aid tool to motivate this child in completing exercises"
	Others	3	"Good additional feature of being able to change exercise speed mid-session"

To the third question; **Which is the most important feature that should be fixed or implemented as soon as possible**, 9 surveys provided a response. Physiotherapists mostly reported system or hardware failures encountered during their session. The four issues noted were: more battery life, SAR hip joint noise, the robot not recovering from falls, and failure with an exercise demonstration (due to the motors overheating). Flexibility/Adaptability was mentioned in 3 surveys, for instance: *"Flexibility of use during session. E.g: if an exercise doesn't work, or too hard/too easy (PT-A)"*. Responses to this question also included system improvement suggestions such as a desire for increasing the variety of patient motivation statements, improving the communication with the patient such as the robot being able to have a conversation with the patient; and providing more information about the session to the participants such as the list of exercises to be done.

Physiotherapists were also asked to **rate the patient in the session** in the fourth question. Fourteen surveys reported positive reactions to the patient's performance during the session, with responses about different patients such as: *"Enjoyed session, maximal participation (PT-A)"*; *"Good - compliant with program/exercises (PT-B)"*; *"He seemed very interested and motivated by the robot (PT-E)"*. In 4 surveys, therapists also compared the patient's attitude to other sessions without the robot. For example: *"He performed well in session. Complied with exercises that are often difficult to convince him to complete (PT-D)"*; *"He did the exercises better than he did previously, however he became distracted throughout (PT-H)"*. However, negative patient reactions were also reported in 3 survey responses, with responses such as: *"Very poor compliance. [The robot] escalated patient's behaviour issues (PT-B)"*; *"Difficult behaviour to manage when trying challenging/new activities. Extremely difficult to reason with (PT-C)"*. Two surveys also reported patient's fatigue during the session: *"[Patient] was very fatigued, not as interested as usually is (PT-F)"*.

The last question of the open survey gave physiotherapists the **freedom to add anything else about the session.** Seven physiotherapists filled in this question. The most common pattern, found in four questionnaires, was about the robot helping the patient making the session more enjoyable. For example, *"It was a great tool to motivate this child in completing exercises (PT-B)"* Other physiotherapists took the chance to explain system errors, or mistakes made during the session: *"During the session, the robot 'broke' - demonstrations started to play up (PT-C)"*; *"I didn't realise that the robot would lie down on its own, so attempted to put the robot into supine, but it then got stuck. Needed the researcher to come and fix it (PT-E)"*. Also another response acknowledged small system improvements that became available during the course of the study, such as on-line exercise speed adjustment: *"Good additional feature of being able to change exercise speed mid-session (PT-A)"*.

5.4.2 Parents' Open Ended Responses

As described in Section 5.1.4, all parents in the study completed the after-observation version of the open question survey. Two parents provided more data after observing a session for the second time, however, responses were counted only if they differed from their previous questionnaire. Parents who then participated in a follow-up session operating the robot themselves filled out a modified version of the questionnaire specifically addressing their experience operating the robot.

Table 5.20 provides a summary of the parents' responses after observing. Parents' responses after operating are presented in Table 5.21.

Parent responses after observing a session

Table 5.20: Parents' open ended responses after observing a session. Number of the question (Q. No); the pattern found; the number of occurrences for that pattern (Occ.); and an example.

Q. No	Pattern	Occ.	Example
1	Positive emotions	9	"[The robot] made it fun and different from everyday therapy"
	Engagement/Focus	8	"It [the robot] had my child's attention the whole time"
	Guidance/Technique	6	"It ensured [patient] did the exercise more effectively"
	Demonstration	5	"It [the robot] shows the exercise is easy to watch and follow"
	Robot gender	1	"OK, however, it needs to be a girl robot, too manly"
2	Yes	17	"I would be fine without [a physiotherapist present]"
	No	3	"No... Depends on the severity and what I need to do with my child. [...] Maybe over a couple of sessions"
3	Responsiveness	5	"Level of interaction - kids are used to 'siri' who 'talks' with them"
	No need for improvements	4	"Nothing, it all worked very well and [patient] really enjoyed it"
	Already Implemented	4	"Vary speed"
	More Exercises	3	"It would be adding as many exercises as possible"
	Colour/gender	2	"Would be nice to have a pink version for females"
	Other mentioned once	5	"Say [patient's] name correctly"
4	Nothing bad	10	"Nothing"
	Speed of exercise	2	"Speed of exercises"
	Other mentioned once	5	"I was worried [the robot] was going to fall off the table and smash"
5	Positive session	16	"The session went very well. My child was engaged, interested and happy"
	Info about the session	2	"Though she [patient] got distracted with many questions, she did the therapy without getting upset. Loved it"
	Patient's behaviour	1	"Yes the colour was blue, need to change the colour because my daughter wanted a girl on"

The first open ended question of the survey asked parents if they **thought the robot was useful in the observed rehabilitation session of their child**. All the recorded responses agreed that the robot was useful, however highlighted different aspects. The most common theme was positive emotions, which appeared 9 times with responses mentioning fun, happiness, or the pleasant vibe the robot brings into the session. For example parents reported that: *"It [the robot] made my child happy"*; *"[The robot] made it fun and different from everyday therapy"*; *"It [the robot] was a different and exciting thing for her to engage with"*; *"The robot has great potential to create a more functionally pleasant environment"*; *"Her mind was taken off [from the therapy] with the robot"*.

The robot helping to engage the child was the second most common theme related to the robot's usefulness, reported 8 times by the parents. Some examples are: *"It [the robot] was very engaging"*; *"[The robot] kept my son motivated and interested"*; *"It [the robot] had my child's attention the whole time"*; *"The robot adds another dimension to physio sessions. Particularly for children who need to do frequent exercises which can be challenging for parents to maintain continued participation"*. A parent suggested the robot may also be useful for home therapy: *"I can see its potential to help my daughter be more independent in complementing physio at home"*. Parents also mentioned in 6 surveys that the robot was useful because it provided patients with guidance when doing the exercises. For example: *"Good to help with slowing down the exercises, so they aren't rushed"*; *"The exercises were all done efficiently and effectively"*; *"Good to have reminders of each exercise and a pace set"*. The robot demonstration of the exercises was also mentioned in 5 surveys as a useful feature: *"The robot was useful because she can demonstrate the exercises"*; *"It [the robot] shows the exercise [to do, and it] is easy to watch and follow"*. The only non positive comment in response to the robot's usefulness was because the robot was identified by the participants as male: *"OK, however, it needs to be a girl robot, too manly"*.

Parents were asked if **they would feel adequately prepared after some training to use the robot by themselves without a physiotherapist**. Seventeen responses were affirmative, with three responses adding specific qualifications to their preparedness: *"If the robot was pre-programmed with the exercise regime I would be happy to use"*. *"Yes if I had some practice"*. *"Most definitely if programmed with exercises I would love it. Looks and seems easy to use"*. Notably, three of the 20 responses to this question were negative, with two responses indicating a clear priority on therapists being present if the patients' needs are high. For example: *"No, not alone. When feelings are involved I think the therapist needs to be there to give advice and options to assist with the patient's struggles"*; *"No... Depends on the severity and what I need to do with my child. [...] Maybe over a couple of sessions"*.

To the question of **What things about the robot could be added, changed, or fixed to make the robot more useful to you and your child's rehabilitation**, five surveys emphatically noted the need to improve the responsiveness of the robot. For example, one parent noted that if the robot could *"somehow know when a patient is showing reluctance"*, then its effectiveness would be improved. Another parent simply noted the *"Level of interaction"* needed to be improved, implying a clear priority on interactivity with the patient. Related to responsiveness, 3 surveys suggested alternative ways of interacting, for example: *"Perhaps a remote button so kids could tap [the robot's] head easily"*; *"Work on the voice control"*. Interestingly, four responses indicated no need for improvement, with one response indicating: *"I think so far the robot is just perfect for its purpose"*. Parents also asked for capabilities that were already in the system, such as online exercise speed variation and the ability to configure *"alternative sessions to keep kids engaged"*, emphasising the need to inform parents of all available features during training. Three responses asked to add more exercises into the system, so they can have longer sessions. Improvements related to the robot's perceived gender were also suggested twice, such as offering a more feminine version with pink colouring. Other general suggestions to improve the system (mentioned only once) were:

- Exercise explanation so parents can explain exercises to their child during the rehab.
- Correct pronunciation of the patient's name.
- More variety of utterances.
- Advising the number of exercises to do before starting the session.
- Referring to the robot execution of an exercise: *"the robot leg touch the ground"*.

The fourth open question asked explicitly for negative aspects of the robot: **What things about the robot don't you like? Why?**. Ten of the recorded responses listed no negative aspects to the robot in therapy, with statements such as *"None"*, *"Nothing"*, *"N/A"*, and also *"I liked the robot, there was nothing I didn't like about the robot"*. Two responses offering negative aspects of the robot were related to the speed of the exercises. For example: *"It perhaps needed to be set to a faster speed so my daughter was more fully engaged instead of having to wait"*. Other different responses mentioned once were: a parent that perceived the robot being *"Direct[ed] towards boys"* and not girls like their daughter; *"It can't help with a patient's emotional needs"*; *"I was worried she [the robot] was going to fall off the table and smash"*; *"Potential technical glitches"*. Finally, one response expressed their concerns about using the system without physiotherapy supervision: *"If the parents are inexperienced, then using the robot without physio wouldn't be viable as how do we ask questions & know if we are doing it correctly & what needs to be improved for our child"*.

The last open question of the survey asked participants to **write any extra comments they wanted to say about the session**. Sixteen of the survey responses provided positive comments about the session such as: *"It was an amazing session"*; *"It gives a great positive vibe to the physio session"*; *"We enjoyed it"*; *"It was brilliant and motivating"*. Two of those sixteen responses also included extra information about the session: *"The type of movement and dynamics of the session helped to identify with therapists where she (the patient) was struggling"*; *"Though she (patient) got distracted with many questions, she did the therapy without getting upset. Loved it"*. One response provided a justification for the patients behaviour: *"Yes the colour was blue, need to change the colour because my daughter wanted a girl one"*.

Parent responses after operating the robot

Eight surveys were collected from parents after operating the robot. Table 5.21 provides a summary of the responses provided by parents in this condition.

Table 5.21: Parents' open ended responses after operating the robot. Number of the question (Q. No); the pattern found; the number of occurrences for that pattern (Occ.); and an example.

Q. No	Pattern	Occ.	Example
1	Some level of confidence	4	"With experience and use I have gained a lot of confidence when working with the robot"
	Unconfident	1	"Because the therapists knows what to do in case anything happens"
2	No Impact	2	"The robot worked very effectively today"
	Minor Impact	2	
	Significant Impact	2	"During the side lying leg lift [exercise] I needed to hold the robot in a side lying position. This prevented me from correcting [my child]"
3	More training	2	"More instructions preceding an exercise as to when I will need to press the robot's head"
	Session Information	1	"I would like a list of exercises in advance being with me"
	Other mentioned once	3	"To use wireless remote to operate Rosie [the robot]"
4	Increased trust	3	"Yes. By using the robot independently has helped me a lot"
	Not increased trust	2	"Not really"
	Other	1	"Yes, however my child gets distracted with me, cheeky, and 'cheats' "
5	Fun	3	"Provides fun and variety to the session"
	Engagement	1	"The robot made my child want to copy the exercises it was showing him, without arguing"
	Motivation	1	"Motivation"

After delivering rehabilitation session to their child, parents were asked about their **confidence using the system**. Four responses expressed some level of confidence, with

2 responses indicating they were completely confident, with reasons such as: *"Previous session gave me confidence"*; *"I felt much more confident. I am learning that I can move the robot around even when it is not performing as usual"*; *"With experience and use I have gained a lot of confidence when working with the robot"*. Only one response indicated lower confidence due to their lack of experience either using the robot or delivering therapy, noting: *"Because the therapist knows what to do in case anything happens"*.

Parents who operated the robot were also asked **how the robot impacted on the level of attention they could give to their child**. Two recorded responses indicated *"No Impact"* mentioning that: *"The robot worked very effectively today."*; *"I was confident to operate with Rosie the robot, but wasn't sure if I was helping [my daughter] with her therapy correctly at times"*. Two responses indicated *"Minor Impact"* without adding any comments, and 2 more indicated *"Significant Impact"*, one of the reasons provided was: *"It (the robot) kept my child captivated at all times. He was looking at it, watching and observing"* suggesting that the robot had a positive impact on the session. The other survey indicating *"Significant Impact"* was due to a robot malfunction: *"During the side lying leg lift [exercise] I needed to hold the robot in a side lying position. This prevented me from correcting [my child]."*.

We asked parents **what training or what things about the robot could be added, changed or fixed so they can use the robot independently**. Two responses suggested more training with the robot was needed: *"More instructions preceding an exercise as to when I will need to press the robot's head"*. One response asked for more information about the session: *"I would like a list of exercises in advance being with me [and to know] what exercises we are going to do today"*. One parent noted their lack of confidence when delivering exercises to their child, stating *"I need to be confident with my child's needs and my ability as 'physio' in order for my child to improve"*. Other single survey responses noted a desire for framing: *"To use wireless remote to operate Rosie [the robot]"*; and *"Nothing, it was great today"*.

To the question **Did operating the robot improve your trust in the system?** 2 responses did not indicate an increase of trust in the robot without providing any further explanation. However, three responses claimed that their trust increased with experience. For example, *"Yes. Using the robot independently has helped me a lot"*. Another parent responded: *"I now feel much more confident and less afraid of breaking it."*. A parent commented that even though she gained more trust in the system after operating it, her child played her off when operating the robot without a physiotherapist. *"Yes, however my child gets distracted with me, cheeky, and 'cheats' if she can get away with it."*. This suggests that while trust in the system is important, the parent-child relationship is another important aspect to consider.

The last question asked parents **how the robot assisted their child during the rehabilitation session**. The most common theme found in three survey responses was fun: *"Provides fun and variety to the session"*; *"Its a break from the monotony. Makes it fun and interactive"*. Other single occurrence responses included: *"Kids get attracted to toys. So, the robot made my child want to copy the exercises it was showing him, without arguing"*. Another survey response indicated that the robot assisted their child by *"Motivation"*.

5.4.3 Patients' Open Ended Responses

As described in Section 5.1.4, thirteen patients deemed cognitively capable by their therapist and parent completed the whole questionnaire (surveys and open-ended questionnaire). Two more completed only the open survey responses. Seven patients who participated in consecutive sessions filled in additional surveys, however, responses were only considered for the analysis if different responses were provided. Table 5.22 provides a summary of the responses.

The first open question in the survey asked patients if **they would like to do another session with the robot, and why?**. Eleven affirmative responses were recorded, the main reason given being the fun the robot brings into their therapy session. *"Yes, it's fun doing exercises with robot (Rosie)"*; *"She did my exercises and made it fun"*; *"Yes I would, because Rosie was fun and funny with her dance moves"*. *"Yes because I love the robot. I like him hugging me"*. Three patients provided negative responses, two of them teenagers (15 year old female and male) because they preferred to do rehabilitation with a physiotherapist. *"I prefer one on one with a physio so I can have an actual conversation while doing physio"*; *"No prefer to do with physio"*. A 10 year old female considered the robot being annoying. *"No, I would not like to do another session with the robot because it is very annoying"*; One survey provided no response.

The second question asked about **which aspects of the robot they liked the most**. Seven surveys mentioned the final dance reward for completing the session, for example: *"The dance!"*; *"Dance at the end"*; *"The dance moves. Because they're really cool"*. The robot bringing fun into their session was mentioned 4 times. This pattern was related to the entertainment the robot provides with dances or jokes, for instance: *"Its dancing is funny"*; *"Can make kids see the fun side of physio"*. Four patients mentioned technical aspects of the robot as the thing they liked the most. Two teenager patients did not enjoy doing rehabilitation with the robot, so they reported mechanical or programming aspects. For example, *"That it is mechanical so I can take it a part"*; *"Can be programmed"*. Other patients were simply attracted by the sensors or components of the robot: *"The way the robot worked and how it used its sensors and spoke clearly"*; *"The components,*

Table 5.22: Patients' open ended responses. Number of the question (Q. No); the pattern found; the number of occurrences for that pattern (Occ.); and an example.

Q. No	Pattern	Occ.	Example
1	Yes	11	"Yes I would, because Rosie was fun and funny with her dance moves"
	No	3	"No prefer to do with physio"
2	Dance	7	"The dance moves. Because they're really cool"
	Fun	4	"Can make kids see the fun side of physio"
	Technology	4	"Can be programmed"
	Companion	4	"I like that it does exercises with you"
	Demonstration	2	"It showed me the exercises I need to do"
	Personalised	2	"I liked the robot using my name"
	Friendly	2	"It's very friendly"
3	Nothing	7	"No, I really enjoyed working with the robot"
	Speed	4	"Pace of exercises felt too slow"
	Repetitive	2	"Repeating the same words"
	Other mentioned once	3	"I don't like the robot factual mistakes, I don't like robot's voice, I don't like the song"
4	Information	2	"Explain the exercises a bit more and maybe ask if I need to be shown again"
	Nothing	2	"Nothing"
	Responsiveness	1	"Actually listen to me and respond and get facts correct. Know what I'm doing"
	Other mentioned once	1	"Give a high five. Hug me"
5	Fun	7	"It's very enjoyable and fun"
	Nothing	2	"No. Thanks for letting us test her out"
	Critical statements	2	"Better for little kids 5-8 years old"
	Other mentioned once	3	"Does she [the robot] have a brain?"

that the head rotates. Speakers are really cool". The companion role of the robot was mentioned by 4 patients, with examples such as: *"I like that it does exercises with you"*; *"That she [the robot] counted [the exercise repetitions] for me"*. Two patients mentioned the demonstrator role of the robot: *"It showed me the exercises I need to do"*. The robot being personalised was mentioned in two surveys: *"I liked the robot using my name"*; and *"[I liked] how she knew my name"*. Two more survey responses also indicated that the robot was friendly. For example: *"It was polite & friendly"*

Patients were also asked **what things they did not like about the robot**. This question had two empty responses, and another seven explicitly indicating nothing. For example: *"No, nothing"*; *"No, I really enjoyed working with the robot"*. Four patients complained about the speed of the exercises, with three indicating the robot was too slow, e.g., *"I don't like the slowness"*; and, the *"Pace of exercise felt too slow"*; *"The exercises sometimes are too slow for my strength"*. Conversely, one patient thought the robot was too fast: *"While she [the robot] was doing the exercises, she was going pretty fast and didn't give me much time for a break in between"*. The robot being repetitive was also mentioned twice. For example, one patient complained the robot was *"repeating the same words"*. A patient disliked that the robot was telling them what to do: *"Telling me what to do"*. The robot's lack of responsiveness to patient conversation was also noted by a patient: *"She never listens and she never ever ever listens in the whole wide world"*. And about the robot in general: *"I don't like the robot factual mistakes, I don't like robot's voice, I don't like the song"*.

In response to **what extra things would you like the robot to do?**, two patients mentioned the robot providing more information at the beginning of the session or during the session. For example, one patient indicated the robot should: *"Tell how many exercises [we are] going to do before doing"*. Another patient suggested the robot should *"explain the exercises a bit more and maybe ask if I need to be shown again"*. More responsiveness from the robot was suggested by one patient: *"Actually listen to me and respond and get facts correct. Know what I'm doing"*. A variety of other single responses were provided in this question, including: *"I would like 'Rosie' to wear clothes, wear a dress"*; *"Give a high five"*; *"More exercises"*; *"A lot of things. Helping me do puzzles and lego"*; *"Hug me"*. Two patients responded *"Nothing"* and *"I'm not sure"*.

The last question gave patients the **chance to say anything else about the session they wanted to share**. Seven responses were related to the fun the robot brought to their session. For instance: *"It's very enjoyable and fun"*; *"It was FUN!"*. One patient was fascinated by the mechanics of the robot, saying the *"Robot is so cool! I like its motors and components"*. Two patients offered critical statements about the robot in their response. For example, one patient indicated they were only interested in taking the robot apart to figure out how it worked. Another patient (aged 15) suggested that the robot was not appropriate for their age: *"Better for little kids 5-8 years old"*. Other comments found in the last question of the survey indicated general enjoyment and interest in the robot. For example: *"I really enjoyed working with the robot. It was weird at times, but over all it was fun"* *"She [the robot] is lovely"*; *"Does she [the robot] have a brain?"*. Two responses indicated that they didn't have anything else to say, and the question was left empty in two more surveys.

5.4.4 Discussion

The results of the study presented in this chapter provide a clearer understanding of what a SAR in this context of paediatric rehabilitation needs to be. The different layers of data collection (Acceptance, Godspeed, and Open ended questionnaire) provide a holistic picture of the needs of the system. The qualitative feedback in this section not only supports the results from the previous sections, but also sheds light on the reasons behind the previous results. This subsection will outline the findings from this Phase 2 study evaluating the SAR prototype for paediatric rehabilitation.

Evidence from both the Acceptance questionnaire and open-ended feedback supports the general conclusion that overall each participant group perceived the robot as useful (PU). In general, patients reacted positively and performed well during sessions with the robot, with several therapists noting observed improvements in exercises completed by patients known in general to be resistant. Formal evaluation with 20 patients in 41 sessions not just confirms previous work in the literature of SARs, in which previous experiments with normally developed children [67], or studies with few patients [132, 176] suggested a SAR can be useful for rehabilitation purposes. These findings have also contributed to providing a clear understanding of the design of SARs in paediatric rehabilitation.

In general, each participant group found the robot useful because it motivates the patient, brings a good vibe into the session or they enjoyed doing rehabilitation with it. Thus, the design of SARs for the paediatric population must include fun aspects in order to engage them. One clear example reported by patients was the final dance routine the robot does at the end of the session as a reward. Other aspects of the robot's usefulness were the robot joining in with their therapy (companion role), through exercise demonstration (demonstrator role), and concurrently performing the exercises and counting each repetition.

The roles of the SAR in rehabilitation (Section 3.1.7) have been accepted and well received by all the participants. The Perceived Intelligence results in the Godspeed questionnaire already indicated participants largely accepted the roles of the robot as a demonstrator and coach, the open ended responses also confirm those results. The two roles that attracted the most physiotherapists were the robot being able to demonstrate exercises (Demonstrator role), and the robot being able to keep the child engaged and motivated (Motivation role). Parents also reported that the robot helped in engaging and motivating their child. The companion role and personalisation of the robot were aspects patients liked the most. Three patients and two parents complained that the robot was too slow for them or their child. Patients are supposed to follow the robots' pace as prescribed by their physiotherapists, slow exercises are harder for the patients. With respect to the companion role, some younger patients (less than 13 years old) were observed to exhibit genuine affection towards the SAR, through gestures such as wanting to hug the robot, or saying goodbye at the end of the session. In contrast, adolescent patients (13 years or older) exhibited less emotional connection with the robot, but in some cases, interest in the technology itself. Those observations contrast with the results of Weiss et al. [244] in a study with the AIBO robot in which children showed more emotional affections than adults. Similarly, Forlizzi and DiSalvo reported that if a robot is perceived sociable (for example the Roomba vacuum cleaner), users can get emotionally attached [60]. In the study presented in this chapter, not all patients perceived the robot as sociable (PS 67% of positive responses) and there was little evidence of strong emotional attachment, although time with the SAR was quite limited. Phase 3 may shed more light on this aspect of the SAR's impact during therapy.

The review of the literature (Chapter 2) on SARs in paediatric rehabilitation noted that most studies with SARs have interacted with children [67, 78] rather than adolescents. Adolescents in general have used other engagement tools in rehabilitation such as video games [87], or virtual reality together with a SAR [70]. Adolescents that participated in this Phase 2 study generally indicated that the robot was not appropriate for their age, and noted its inability to hold a conversation with them. This would appear to indicate that older children seek more direct and meaningful social interaction in their sessions than younger children. Therefore, they preferred to not do another session with the robot, and reported mostly technical aspects being what they liked most about the robot.

Another patient also reported the robot as annoying after the completed session, identifying the robot's lack of responsiveness, repetitive speech, and incorrect speech recognition. Those issues were reflected in the responses of Social Presence (SP) and Animacy (ANIM) constructs in the Acceptance and Godspeed survey respectively. A SAR perceived as repetitive can be rejected by the participants, thus, the design of the speech delivery should be carefully considered. Avoiding non-repetitive speech is made extra challenging in the context of repeated exercise demonstration and guidance due to the labour intensive task of providing the robot with sufficient choices of speech to deliver relevant to each exercise. The observations in this study indicate that the perception of repetitive speech can be improved by delivering shorter sentences. For instance, delivering a statement such as: "Good job!" two consecutively times after each repetition was not perceived as being repetitive. Indeed, session observations noted that therapists deliver such statements very frequently in rehabilitation. However, longer, more explicit sentences such as: "Every exercise we do, it gets us closer to my awesome dance moves. Keep it going!" were clearly perceived as repetitive if even mentioning only twice in a session.

Additionally, changing the sound qualities of the delivery speech may also mitigate issues of perceived repetitiveness. For example, changing the emphasis of words in a sentence. While not explored in this thesis, such research is clearly of value to human-interaction systems in such contexts.

Parent and physiotherapist feedback also indicates a desire for more responsiveness and adaptability to changing patient needs. Examples are the robot not reacting to a patient with a lack of stamina, patients that clearly disliked the robot, or participants asking the robot to repeat the last explanation. This lack of social awareness clearly impacts the acceptance rate of a SAR. Previous studies already suggested that the social abilities of the robot affects social presence, and thus the enjoyment [86]. Notably, despite these expressed deficits, perceptions of the system's usefulness and likeability appeared to not be significantly impacted. This may be due to other perceived benefits such as the robot's novelty and motivational qualities, but also may be attributed to participant's belief that such issues are likely to be overcome in the near future.

The colour of the robot was reported to cause rejection due to its associated gender. Two different NAO robots were used in this study: a royal blue version 5 named 'NAO' which did 4 rehabilitation sessions before being replaced due to hardware issues, and a teal blue robot version 4 named 'Rosie' used for the rest of the study (37 sessions). All feedback relating to the desire for a "female" robot was only recorded using the version 5 robot referred to as 'NAO' in the study. Once replaced by 'Rosie', no such feedback was given. A study about gender segregation with 74 children and a NAO robot reported minor differences between the different conditions in a pretend play scenario: girls or boys interacting with a female, or male robot. However, the authors reported two strong negative reactions from boys with the female robot [192]. Those cases are similar to the one reported in our study in which a female patient expressed a strong rejection of a male robot. It was out of the scope of this study to explore if the gender of the robot really effects participants' perceptions of the robot, however the observed impact indicates it is an important factor in the design and development of the SARs in paediatrics. It is an open research question as to whether the gender of the robot has any effect on compliance in rehabilitation. In this particular study, a neutral gender colour and a female name for a SAR delivering rehabilitation did not cause rejection or negative comments about its gender. Technology developers aiming to design SARs to interact with the paediatric population should carefully consider the colour and the gender traits of the robot.

It is well established that experience brings confidence with the use of technology [124]. In this study the Acceptance questionnaire showed that generally the robot was perceived to be easy to use (PEOU) by therapists and parents who operated the robot. Similar results are reflected in the responses of the open questionnaire, in which most of the parents (17 out of 20) agreed to participate in a future session operating the robot without a physiotherapist present, supporting the robot was perceived to be easy to use. Parents who operated the robot in general reported in the open questionnaire that they gained confidence operating the SAR by: observing the first session of their child with a physiotherapists and the robot, and with the experience of using the robot in the second session. Similar results have been reported about trust.

A parent reported that they did not feel more confident after using the robot due to their lack of knowledge in physiotherapy. This suggests that training to parents is not just about the robot, but also about the exercises being delivered to their child. Parents of inpatients are usually trained to help their child to do their exercises after hours. However, this might not be the case for outpatients.

The training to participants in order to use the robot was limited, it provided only an overview of the robot's operational requirements. Ideally operators of the robot should go though all the different capabilities of the robot in a therapy session. In the case of the prototype SAR: pausing the robot, changing its speed, and dealing with loss of stability. Training for parents consisted only of the observation of a session being delivered by their child's physiotherapist, and the same 5 minute brief introduction as given to physiotherapists before operating the robot. Although the Perceived Ease of Use (PEOU) results indicated that this training was sufficient for participants to make effective use of the SAR, parents were not completely aware of the robot's capabilities. For instance, over half of parent participants suggested more training with the robot would have been desirable, along with more information about the session.

This formal evaluation phase (Phase 2) of the SAR has brought new outcomes in order to improve the prototype for on going clinical deployment. Table 5.23 provides a summary of the main issues identified that affected the acceptance of the robot during the in-situ evaluation of the prototype. The table also indicates how those issues have been addressed, if possible, in order to integrate the robot for ongoing clinical deployment.

5.5 Limitations

This subsection presents the limitations of the Phase 2 evaluation presented in this chapter. As an in-the-field evaluation, data collection and analysis is necessarily limited in the generalisations it can support, however it is argued that the authenticity of the study environment, and the richness of the data collected does offer significant insights into the deployment of SARs in busy clinical environments.

Recruitment of Phase 2 study participants has been unavoidably biased towards patients judged by their therapist to possibly benefit from use of the SAR. Parents and/or patients not invited or not wishing to participate may have provided additional insights

Table 5.23: Summary of the prototype issues affecting the acceptance of the robot, and how we address them for deployment.

Issues from Phase 2	Improvements for ongoing deployment
Repetitive Speech (ANIM, PENJ)	More variety of utterances with shorter sentences
Neutral Intention of Use (ITU)	Tablet interface to allow participants to configure and start the robot without technical support
Incorrect speech recognition (SP,PENJ)	The speech recognition will be very limited, and the robot will offer alternatives via head-taps.
Colour/Gender of the robot	The next study will make use of NAO V4 which have more gender neutral colours than NAO V5
More information about the session (PEOU)	The next study will provide participants the list of exercises to be done in the session
Not enough training for parents (PEOU)	The next study will include more training to parents
Technical Failures	The prototype in the next study will not go though modifications,running a stable version of the system
Robot falls	Shorter sessions will prevent motors overheating. The robot will provide alternatives to change posture
Lack of responsiveness or able to hold a conversation (SP, PENJ)	This is one of the biggest challenges in the Human-Robot Interaction field
Lack of responsiveness to the patient's mood (PAD)	Social awareness is another challenge unsolved in the Human-Robot Interaction field
Monitor the patient Provide real time feedback (ANIM)	The use of external sensors such as 3D cameras are not desirable for the ongoing deployment of a robot in a busy hospital setting

not captured in this study. In particular, perceptions of usefulness may have been less universally positive. However, it could also be argued that such case-based choices reflect more accurately how therapeutic aids are selected by therapists. Notably, on two occasions it was observed that parents were more interested than their child in participating in the study. Parents sometimes were observed persuading their child to try at least one session with the robot. While these cases were rare, they provided some diversity in the pre-study enthusiasm of patients who participated in the study.

If participants expressed an extreme adverse reaction to the robot, then the session was immediately cancelled, thereby possibly limiting the data collected in terms of observations, and patient's questionnaires. Such cases provide valuable insights into the diversity of responses to the SAR, but had to be balanced with the clinical and ethical requirements of the study.

As an in-the-field study in a busy hospital, data collection was adapted to suit each participant group. In some instances, this led to questionnaires not being filled in immediately after the participants' interaction with the SAR due to patients and parents attending other appointments immediately after the SAR-assisted rehabilitation session. In such instances, questionnaires were given to be filled out at a later time, however five questionnaires were not returned. In some cases, parents were not able to attend the rehabilitation sessions of their child due to different commitments.

The young age of most patients, or their medical condition, also limited the number of questionnaires that were collected. However, researcher observation notes in combination with therapist's and/or parent's questionnaire responses were generally able to capture the overall patient experience with the SAR.

The limited number of available therapists who participated during Phase 2 (N=8), and also that only one single hospital was considered, are limitations of this study. Only a limited number of therapists were able to be recruited into the study, this was a practical limitation dictated by therapist availability, and their roster, and thus unavoidable. Conducting a similar study across multiple sites is a possible way to increase therapists. This would also assist in generalising these findings to other sites, where environmental and operational factors may impact user perceptions of the SAR.

5.6 Summary

This thesis explores the design, evaluation and integration of a general-purpose social robot into existing paediatric clinical practice for ongoing clinical deployment. Previously the in-situ design process has been explained, in which a set of basic roles, requirements, and design decisions for a SAR in paediatric rehabilitation were derived (Chapter 3). The first prototype has been iteratively developed as explained in Chapter 4, and evaluated in-situ.

This chapter evaluated the robot prototype in terms of participants' perceptions of the SAR, with focus on its acceptance as a therapeutic aid at the Royal Children's Hospital in Melbourne, Australia. During this phase, in accordance with Phase 2 of the in situ design process, the robot delivered 41 rehabilitation sessions to 20 different patients. Eight physiotherapists (6 fully qualified physiotherapists, 2 physiotherapist trainees) used the robot; 20 parents attended the rehabilitation session of their child; and 8 of them later operated the robot to deliver therapy to their child. This study has established a clear list of system development and research priorities that must be addressed to fully realise on-going and effective deployment of the SAR.

Overall, the results presented in this chapter provide strong support for the acceptance of the SAR as a therapeutic aid. In general, physiotherapists and parents perceived the SAR as useful, and expressed a positive attitude towards using the robot in rehabilitation.

Despite only limited training and exposure, therapists and parents who operated the SAR perceived the robot as easy to use. Moreover, multiple sessions appeared to either maintain these levels, or improve on them. Parents in particular, despite not having any formal training, exhibited confidence and competence when operating the robot. A majority of patients liked the robot helping them in their rehabilitation, indicating that it was because of the fun the robot brings into their session.

As stated in Chapter 1, the aims of the SAR is to support therapy delivery without physiotherapist supervision, in an on-going clinical capacity. Thus, the next chapter (Chapter 6) explores what metrics can be used to evaluate the success of a SAR when delivering rehabilitation therapy without physiotherapist supervision. Specifically, results from post-Phase 2 interviews with physiotherapists are presented to determine appropriate metrics, which will guide the evaluation in Phase 3 of this study, exploring the on-ward integration of the SAR (Chapter 7). The chapter will also explore how the use of a semi-autonomous robot has impacted care delivery for physiotherapists who participated in this Phase 2 evaluation of the SAR.

Chapter 6

Evaluating the Clinical Integration and Impact of a Socially Assistive Robot on Rehabilitation Care Delivery

Previous chapters have presented and evaluated a Socially Assistive Robot (SAR) prototype in the context of clinical use. These chapters focused on the operational performance of the SAR, and perceptions of the SAR from the perspective of the system's three main user groups: parents, patients and therapists. With the goal of integrating the social robot in a existing clinical practice for ongoing clinical deployment and in accordance with Phase 3 of my design and evaluation methodology, in this chapter I seek to evaluate the prototype SAR in daily use in an on-ward hospital setting without technical support.

Phase 3 of the design process aims to evaluate how the SAR prototype performs and integrates in the clinical programme of selected patients. This phase will take the form of case studies with parents operating the robot during a week. A key component of this phase is evaluating care delivery using the SAR, without technical support, with the aim of gaining a deeper understanding of what impact a SAR has when used to augment the traditional care delivery model. Such an evaluation, however, requires appropriate metrics derived from appropriate expertise.

To this end, this chapter proposes an evaluation method via observations to assess the quality of a rehabilitation sessions delivered without a trained physiotherapist present. Specifically, it is intended to apply an Objective Structured Clinical Examination (OSCE) which is a common type of examination used to evaluate the skills of health science candidates, for example: dental [198], nursing [187], physiotherapists students [161], or surgical residents [205]. Most commonly, the candidate is evaluated by independent examiners via observations, using a checklist of items to be performed by the candidate. This chapter seeks to derive such a checklist for Phase 3 evaluation.

To derive appropriate metrics, physiotherapists who participated in the previous study (Chapter 5) were recruited to participate in a follow up study consisting of individual semi-structured interviews. From a thematic analysis of interview transcripts, a checklist of observable items has been generated, from which a form has been produced for evaluating the quality of paediatric rehabilitation care delivery. This form was employed in case studies presented in the next chapter (Chapter 7)

As a follow up of Phase 2, in the presented interviews it is also examined therapists' perceptions of the SAR's impact on their care delivery during Phase 2. As explained in Section 3.3.8, while general-purpose robots such as NAO offer a highly degree of autonomy, they typically require assistance, either by design, or due to error. Extending this, this chapter also explores the cost-benefit trade-off through targeted post-Phase 2 interview questions with physiotherapists.

The novel contributions of this chapter are:

- An Objective Structured Assessment form to evaluate the success of a SAR in delivering paediatric therapy without physiotherapists supervision.
- Physiotherapists' insights of the inclusion of a semi-autonomous robot which needs assistance in their paediatric rehabilitation sessions.

This chapter is structured as follows. The method of the study is explained in Section 6.1. The analysis of the interviews regarding to the impact of the robot in rehabilitation, and its discussion, is presented in Section 6.2. The analysis of the interviews regarding the evaluation of a successful session in rehabilitation is presented in Section 6.3, Section 6.4 derives the evaluation method for Phase 3 study from the interviews. The limitations of the study are clarified in Section 6.5. Finally, a summary is presented in Section 6.6.

6.1 Method

Semi-structured interviews were carried out after the Phase 2 study (June 2018) in preparation for Phase 3 study on-ward integration of the SAR. This section explains the method of the post-study interviews conducted in this study, including participant selection criteria and questions covered during the interviews.

6.1.1 Participants

Physiotherapists employed at Melbourne's Royal Children's Hospital and who participated in the Phase 2 evaluation (Chapter 5) were deemed eligible for selection. Of the eight physiotherapists who participated in Phase 2, four physiotherapists were recruited. Two physiotherapist trainees, and two fully qualified physiotherapists were not available to participate because they were no longer working with the rehabilitation department of the hospital. Specifically, physiotherapists PT-A, PT-B, PT-D, and PT-E from Phase 2 were available to participate, and were contacted via email with the details of the interview.

It should be noted that post-Phase 2, the SAR remained available at the hospital for general use by therapists. During this time, Physiotherapists PT-A, PT-B, and PT-D used the robot (Prototype Version 1.0.0) independently with the tablet interface, interview responses to questions of the SAR's impact were likely influenced by experiences with the SAR outside of the formal Phase 2 study.

6.1.2 Semi-structured Interview

Interview questions were provided in advance of the interview by email in order to allow participants time to consider their responses. The interview was composed of 3 parts: Part A, Part B, and Part C. Part A aimed to derive metrics to evaluate the performance of parents when guiding physiotherapy sessions using a traditional print-out of exercises. This was included to assist in identify any potential differences in observable metrics when conducting therapy sessions in a traditional manner, versus with a SAR. Part B asked physiotherapists to list any changes to their responses to questions in Part A when considering parents guiding physiotherapy sessions with the prototype SAR. Part C focused on the interviewees experiences with the SAR, and in particular, the impact the robot had on their care delivery.

We now list the questions asked during the interview:

PART A: Parents delivering therapy with a print-out

- Parents of some in-patients are given a print out with a list of exercises to be done after hours (i.e: evenings, or during the weekend). If you were observing a parent guiding physiotherapy sessions in the case described, how would you know if the parent was delivering the therapy correctly? How would you evaluate how well the parent is at delivering the therapy?

- Can you list in order of importance all the signs that you would look for to indicate to you that the parent is effectively delivering the therapy?

- Can you list in order of importance all the signs that you would look for that would indicate that the session is not working, or the parent is not successfully delivering the therapy?

PART B: Your observations of parents with the robot

- If parents use the robot instead of a print out, and there are no system failures or technical disruptions, would your responses to any of the previous questions change? How? Please ignore system errors and focus on the parent delivering the therapy.

PART C: Your experience with the robot

- How much effort was required to help/assist the robot during the therapy session ? How demanding would you consider the robot?
- To what extent did you feel the attention you needed to give the robot impacted on your level of attention to the patient? Were you concerned about this?
- Are there any positive aspects when helping/assisting the robot? Can you list them?
- Are there any times during which you would like to provide more physical assistance for the robot, instead of the robot doing it by itself?
- Did the robot provide clear instructions when asking for assistance? If not, can you provide some examples?
- Did you feel anxious when having to provide assistance to the robot? Can you explain the situation?
- Is there anything you would like to add? Are there any other relevant issues we haven't covered that you would like to mention?

The NAO robot used during most of the Phase 2 study was known by the therapists as "Rosie". Therefore, the facilitator and the participants used the name "Rosie" to refer to the SAR during the interviews.

6.1.3 Interviews

The four interviews were conducted over the phone to facilitate flexibility of scheduling among participants and researchers. Audio from the interviews was recorded and later transcribed. Interviews lasted less than 1 hour, with an average of 49 minutes per interview.

The four interviews took place within a 1 month period (June-July 2018), 7 months after the conclusion of Phase 2.

6.1.4 Thematic Analysis

Interviews transcriptions were analysed following an inductive thematic analysis approach as described by Braun and Clarke [17]. Transcripts of the interviews were independently read multiple times in order to become familiar with the data by two researchers (the author of the thesis, and the facilitator of the interviews). The data were coded independently by the 2 researchers searching for common patterns. Those codes were grouped together into overarching themes, labelled, and represented in a thematic map. For intercoder reliability, researchers compared their codes and reached a consensus about the codes and the themes.

Section 6.2 starts reporting the thematic analysis of Part C, which asks physiotherapists about their experience with the robot in Phase 2 study. After this, in preparation for the Phase 3 evaluation of the SAR, Section 6.3 provides the thematic analysis of Part A and Part B of the interviews.

6.2 Thematic Analysis: Impact of SAR on Care Delivery

Part C asked physiotherapists about their previous experience when using the robot in their rehabilitation sessions. The goal of this part was to understand the perceived impact the SAR prototype had on therapy delivery during Phase 2, from the perspective of the therapists. Three different themes were extracted from this part of the interviews: positive impact of the robot in the session; negative aspects of the robot which has an impact on the rehabilitation sessions; and training to caregivers in order to reduce the negative issues that arose.

Figure 6.1 shows the conceptual thematic map derived from the interviews about the impact of the robot in rehabilitation.

6.2.1 Positive Aspects of the Robot

Physiotherapists in general reported that the robot in rehabilitation has a positive impact on the dynamics of the session if there are no system disruptions.

The engagement of the child is one of the positive aspects mentioned by the therapists.

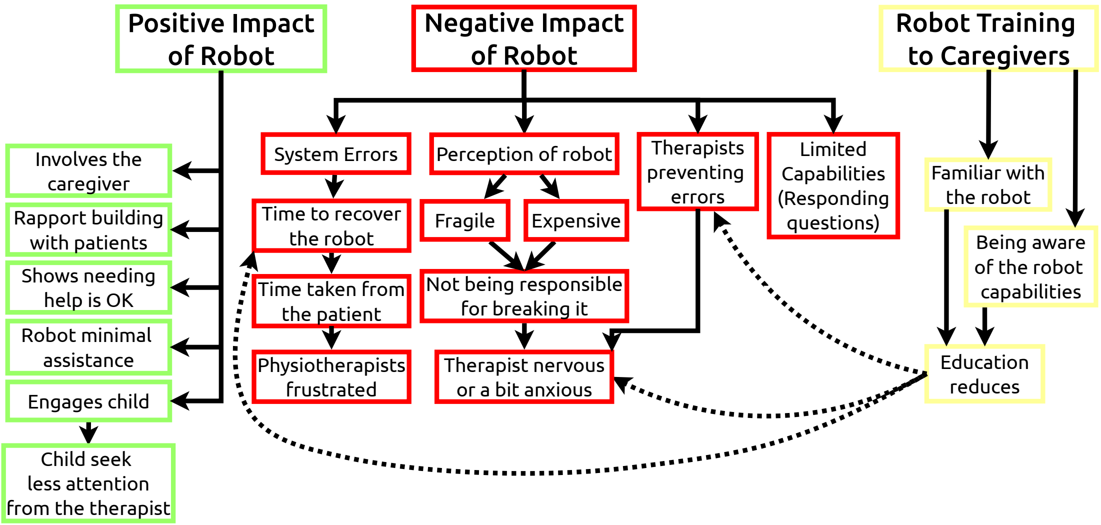


Figure 6.1: Thematic map of the Impact of the Socially Assistive Robot in rehabilitation.

> *The children seem pretty engaged when the robot works. It's a novelty, so you know, it's something fun, and it does actually make them want to do the exercises, and want to copy the robot. [...] It's probably also the first time the parents see it, so the first few times they are also engaged. (PT-E)*

If patients get too engaged with the robot, physiotherapists note that the patients often then require less attention from therapists, reducing their burden:

> *[The child was] quite engaged with the robot and I felt like I was able to provide enough attention to them. Because he was focusing his attention on the robot, he wasn't really looking to me for attention. (PT-E)*

Three therapists reported that if the robot works without any issues, the assistance required by the robot is minimal. In fact, therapists reported that helping the robot often also helped engage the child, and involves the caregiver in the rehabilitation session.

> *I think in terms of helping, having you to be involved in the session is almost a positive... that you're still kind of involved in that, and often you will need to assist helping the child with those things as well (PT-D)*

One therapists noted that assisting the robot shows to the patients that needing assistance is fine.

> *The help is okay, so I think a lot of our kids need help to get up from the floor, or a lot of our kids do need help to get that child tuck in under their knee. And*

> *I think it's fine to show that, and so them to see if helping, you know, something else, not just them all the time. (PT-A)*

Therapists expressed no concerns with any time spent helping the robot come at the cost of time for the patient. Moreover, therapists noted that some patients help the robot themselves when required.

> *Some of them [patients] like to engage and help the robot themselves. So, it's like I can't do it myself, but I can help the robot. (PT-A)*

> *I think when Rosie does needs attention if it's, helping putting things or making sure she's got kind of space, that's not time that you necessarily need to be providing attention to the child either. So, I don't think it impacts on that kind of shared attention or involvement. (PT-D)*

Finally, one therapist noted the robot's ability to facilitate rapport building between patients and the therapist.

> *I think there's been a few kids that Rosie has been very helpful and very good in terms of rapport building. (PT-A)*

6.2.2 Negative Aspects of the Robot

Therapists also mentioned some negative aspects of the robot in their rehabilitation sessions.

One therapist mentioned that even though the robot worked reliably and with no issues in sessions, they felt anxious about the robot malfunctioning, causing some level of divided focus between robot and patent. However, the therapist did not consider the robot to be too demanding.

> *Even if there aren't any technical difficulties, and the patient is quite compliant, everything is going really well, I think I tend to put more attention on the robot because I'm just preempting that something might go wrong. I think the other factor that I'm always sort of considerate of is I know that Rosie is very expensive. [...] (PT-B)*

The robot's perceived expense and fragility was noted by most therapists during interviews. Two therapists reported some anxiety or nervousness when using it for the first time because they were worried about the robot falling.

> *I'm always sort of nervous about doing something that could cause damage. Over the time we've been involved with the robot, quite a few of them have issues and things, sent back and forth for repairs and that sort of thing. So, I think that's probably also my other reason for focusing too much attention during the session on the robot. (PT-B)*

However, with multiple uses and experience, some physiotherapists gained confidence.

> *I think initially [I was] a little bit [anxious]. I think I was worried about it falling. [...] It was a session at the start that I was like I didn't want to be responsible for breaking or damaging the robot. So, I think once you got more comfortable with the robot I realised "Whow! Yeah, occasionally things happen, but overall she is actually quite durable". I think that made it a little bit easier. (PT-A)*

The main concern expressed by all therapists is when system errors occur, or the robot malfunctions impacting negatively on the session. The main issue is the time the robot takes to be fixed, and the time taken from the patient.

> *It happened in other sessions where there has been a malfunction and then, it won't start or gets through an exercise and then doesn't go on to the next one. So, I feel like trying to focus my attention on getting the robot to work again in order to engage the child, I'm not paying enough attention to the child. (PT-E)*

> *When things [the rehabilitation session] don't necessarily go to plan with Rosie [the robot]. In terms of timewise, because then [I need to] be able to kind of reset things. It can be quite tricky at times to negotiate that as well as kind of continuing the session with the child. (PT-D)*

A therapist explained the rehabilitation sessions are limited in time, so disruptions from the robot can have a significant impact on the completion of the rehabilitation sessions.

> *We work in an environment where our sessions are quite limited and we want to make them as effective as possible, particularly if we are providing quite intensive rehab. So, when a lot of our session is then dealing with technical difficulties, or when I'm completing the programme with the child, I do feel my attention is more focused on whether the robot is working properly. I guess my attention isn't as focused [on the patient] as it is when the robot is not present. So, I think that is something that at times I think I am concerned about. (PT-B)*

Two therapists reported being frustrated rather than anxious when the robot simply failed to work properly, such as not being able to start the programme, the robot not following the programme, and thus the child disengaging from the session.

> *[I] tried to programme on the iPad what we wanted to do, and then it didn't sort of follow that. So, I guess yeah it's just sometimes probably more frustrated than anxious. Anxiety is about malfunctioning, and then you sort of lose the engagement with the child, and then the session is kind of over because the child is lost. (PT-E)*

Therapists also noted some negative impact on sessions due to the robot's lack of responsiveness. While therapists agreed that the pre-programmed instructions of the robot are clear, therapists reported that the robot is not able to respond if asking for clarification or to repeat the last instruction if missed.

> *I think if the robot's programmed for particular exercises that require particular instructions, then yes it was programmed with clear instructions (PT-E)*

> *The robot doesn't respond in real time, like it's all pre-programmed instructions. (PT-B)*

One therapist provided an example of why just providing clear instructions is sometimes not enough:

> *I can imagine [for example] if it was loud in the room or something. Because a parent or a therapist didn't hear the instruction, and sometimes it sort of "Ohh what do I do now" because it starts flashing. But, other than that I always knew what it wanted (PT-A)*

6.2.3 Training to Caregivers

Therapists noted that a number of the negative aspects of the robot's impact on sessions were potentially addressable though familiarity and training. For example, one therapist mentioned that being familiar with the system and being able to alter the session has been very helpful to adapt to their needs.

> *I guess that the more familiar you are with that [the robot], and the more familiar you are with kind of being able to work though those different situations, the easier it kind of becomes and the less anxious I am. [...] I think having understanding around how to turn it on, and how to necessarily change the session [...] I think knowing how to potentially change things has been helpful. (PT-D)*

Therapists noted that being familiar with the system provides knowledge of what to expect from the robot. After 1 or 2 sessions, it becomes easier to continue the session even if the instructions from the robot are missed.

> *I think it was easier for me once I was familiar with how Rosie worked. So, after... my first sort of session I think, you know, it was sort of "Ohh what do I do next?". Then you sort of had to quite closely follow what she was saying. Whereas I think once you have done, say 1 or 2 sessions you knew what to expect. And so, I think that made that much easier to follow that through. (PT-A)*

Another therapist mentioned that being aware of the capabilities of the robot is also very important. For example, knowing the robot's physical capabilities can support knowing when to step in in order to help the robot, or stop a potential fall.

> *I think it's important to the therapist and to the parent to be aware of the [robot's] limitations. [...] I think having the training, so that everyone is aware of what physically the robot can actually do [is important]. So, in terms of physical demands on me to operate the robot, I'd say it's minimal, but knowing when to step in to help is the important thing. (PT-E)*

Having the print-out of exercises as a backup plan is what one physiotherapist suggested in case of a major disruption.

> *I think it'd more be sort of planning for those sort of things to happen, having that list of exercises ready, and not just expecting that the robot will deliver everything. [...] Which is what we do with most of technology things these days, you sort of still have to have a back up plan. (PT-A)*

6.2.4 Discussion

This post-Phase 2 interview-based study has explored the impact of the prototype SAR on therapy delivery, and the factors that influence this. The introduction of a semi-autonomous robot that requires human assistance requires careful consideration when used in busy rehabilitation clinics. Thus, the physiotherapists' perceptions of the SAR's impact on their ability to deliver care, and attend to patient's needs was further explored.

Therapists reported that the assistance required by the robot, such as changing its posture, or adding an auxiliary aid is minimal. This kind of assistance does not take therapists' attention away from the child. In fact, therapists reported that some patients actively helped the robot themselves when required. Similar behaviours have been reported in the literature of Symbiotic Human-Robot interaction, in which robots and humans perform collaborative tasks asynchronously [186]. For example, children are generally willing to respond to a robot's request for assistance, particularly when prior permission is given from supervising adult [9]. Hüttenrauch and Severinson Eklundh [93] also report that untrained bystanders are generally willing to assist a robot if the assistance does not interrupt another task.

Physiotherapists reported in the interviews that the robot requiring assistance from the caregiver or the patient offers potential benefits, facilitating active caregiver involvement in the session. Furthermore, the robot's need for assistance can also serve as a model to patients, normalising the need for help when doing their rehabilitation exercises.

The robot can have a negative impact on the rehabilitation session if the therapist is not confident with the robot. Therapists perceive the robot as a fragile and/or expensive device. This can increase their anxiety and the amount of time they dedicate to oversee the robot, potentially taking attention away from the patient. However, therapists mentioned that with experience they became more familiar with the robot, less anxious when using it, and dedicate less time to the robot.

Physiotherapists participated in the study without any prior training, apart from being told that the robot will ask for help from time-to-time. While the robot was perceived as easy to use, and therapists where able to operate it effectively (Chapter 5), the limited familiarity and knowledge of the robot's capabilities can impact negatively on the rehabilitation session due to confusion or an inability to resolve unexpected issues. A more formal and targeted familiarisation training programme should thus be considered in future studies when trying to integrate a social robot in a hospital environment to be used by non-technical users. Such a training programme would likely benefit from a co-design approach, in which therapists with experience with the SAR can ensure crucial knowledge gaps are addressed.

Iterative development and in-situ testing exposes all the system errors in front of all the participants (therapists, parents, patients). During the Phase 2 study, the research engineer (author of the thesis) was available to recover the robot in case of a major system disruption.

At the end of Phase 2 study, the SAR remained accessible to therapists. Three of the four therapists interviewed in this study used the robot by themselves without technical assistance. Notably during this time, early integration issues with the SAR's tablet interface (first introduced in the later sessions of Phase 2) caused disruptions to some of these informal sessions, which evidently has impacted perceptions of trust and acceptance of the system. For example, one therapist during the interview reflected very clearly their experience with the system error, and how the error affected their trust and confidence with the robot.

> *The last experience I had with the robot I had two patients, two twin boys who were quite active, but also quite physically challenged. We sort of used the robot as an incentive for the remaining therapy session. So, it was something that was going to be a reward. We've got the robot set-up, they were set-up, the family were out there with their phones and ready to go, and the robot would just not work! So, I guess that was probably a prime example of when if you use the robot as a big motivation aspect to the child's therapy programme, and is also including the family, as a family they were very excited to complete. And then because of the technical difficulties I ended up spending a lot of that session trying to correct whatever was happening, which probably I wasn't very successful with in the end. And then I got to sort of three quarters of the sessions than I thought. Well, actually, not being effective in this session. (PT-B)*

The therapist noted the time cost and the impact on the rehabilitation session the system failure experienced.

> *So, then I forgot about Rosie and just completed the session that I would have planned, but due to the time that was already taken in all the stuff, I didn't get to complete an effective session so that allocated time. [...] I realised that by trying to get something to help me, I actually ended up spending more time away from my patients when they're actually my priority of the session. So, I think that also then affected my continued use of Rosie because I was sort of like, I don't wanna have to go through that again! (PT-B)*

As explained by PT-B, system errors can have a very negative impact on therapy delivery, especially if the robot is used as the main, or unique engagement tool. Thus, backup plans are very important, technology developers should provide alternatives to be executed in case of a major disruption to allow therapists re-conduct the session.

Notably, while allowing therapists to make use of the SAR outside of formal testing did expose errors, It is argued that such attempts by therapists to use the SAR voluntarily offers significant support to the in situ design process adopted, and in particular, the emphasis on stakeholder engagement. Therapists took a sense of ownership of the deployed system, the robot was available for them, so they used it in their rehabilitation sessions without technical support. The current system has been fixed (V1.0.1) and is ready for the next study.

Overall, these findings suggest that while in situ evaluation of the robot behaviour and impact is effective, traditional software engineering practices and testing should be maintained. These data indicate that therapists are tolerant of the robot's functional limitations, but less so of unpredictable hardware and software failures.

6.3 Thematic Analysis: Evaluating Rehabilitation Care Delivery

The thematic analysis of Parts A and B of the interviews lead to the identification of 5 themes generated from the initial codes for the evaluation of the success of a session being delivered by a parent to their child: Technique, Parents' Understanding, Parent Engagement, Patient Engagement, and Robot Presence. Of these, Robot Presence is the theme which arose when outlining the differences, if any, when evaluating the success of a session being delivered by a parent, compared with the robot. This section describes the identification of those themes.

Figure 6.2 shows the conceptual thematic maps derived from the interviews to evaluate the success of a rehabilitation session delivered by a parent with a print-out of exercises (Figure 6.2a), and with the SAR (Figure 6.2b).

6.3.1 Technique

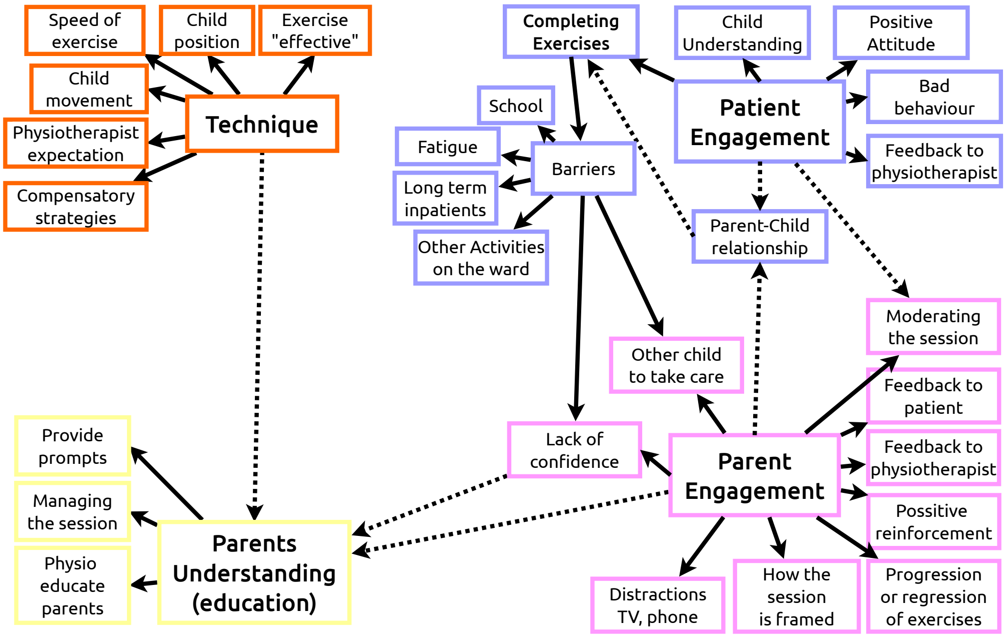
Physiotherapists considered important that in a rehabilitation session the exercises are done with the correct technique.

> *As a physio we are looking at good quality of movement and making sure that things are in alignment. So, we would want to make sure that the exercise was done with the correct technique. (PT-B)*

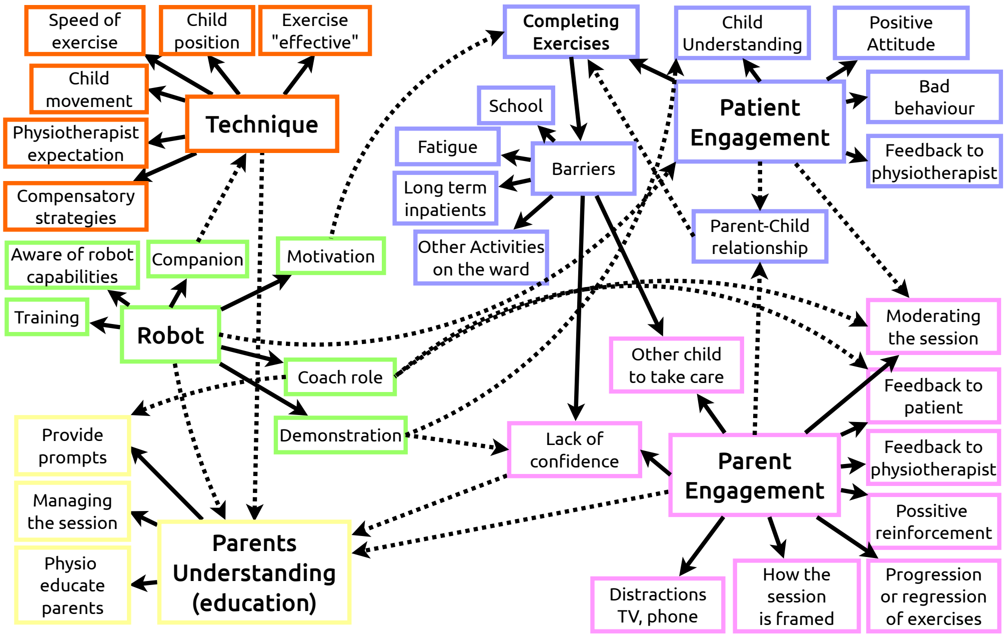
> *The way the child completed the exercises is probably the most important. And that includes like the starting position to set up probably to start the exercises, and the exercises done. I guess at the right speed and with the right technique. So, that's actually gonna be effective. (PT-A)*

An example provided about how patients can do exercises with an incorrect technique is by incorporating other muscles not required to do the task, but that can assist in completing the task.

> *What we say is 'tricking' through incorporating other muscles [...] It's more of a compensatory method. Which most people do when they are doing an exercise because it can be very difficult to isolate the one muscle group that you are trying to do. (PT-B)*



(a) Success of a Rehabilitation session with a print out of exercises.



(b) Success of a Rehabilitation session with the Socially Assistive Robot.

Figure 6.2: Thematic maps of the Success of a Rehabilitation session. (a) With a print-out of exercises. (b) With our Socially Assistive Robot.

Physiotherapists provided examples of how patients use compensatory strategies when doing the ‘leg raise’ and the ‘bridging’ exercise.

> *If they are ... kicking their leg up, they can get that full range that they can do, rather than ... the range that is easy. (PT-D)*

> *With bridging they might try instead of using their bottom to lift their body up, they would try to push with their arms (PT-E)*

The patient’s speed when doing an exercise is another important factor for the success of a rehabilitation session noted by physiotherapists. For example, doing exercises too quickly might be a sign of bad technique.

> *Usually with an exercise we have a sort of set speed in mind that we talked about with the family. So, it might be, you know, you wanna at lift for the count of three, hold for the count of three, and lower for the count of three. Because otherwise, you know, kids all throw the leg up in the air, and throw it down, and you kind of defeat the point of doing the exercises in the first place. (PT-A)*

6.3.2 Parents Understanding

In order to ensure exercises are done with the correct technique, the physiotherapists note the importance of educating parents on the exercises of their child. Thus, parent understanding is the next theme extracted from the interviews.

Physiotherapists noted that they do not just provide parents a sheet of exercises and expect parents to read it and know what to do. Rather, an attempt is made to educate on those exercises when attending the rehabilitation sessions with their child.

> *In terms of correcting technique, I guess what I would do is try running through the programme with the parent before they have to do it by themselves. (PT-E)*

Physiotherapists noted that it is common to provide parents instructions and tips on how exercises should be done. Therapists provide cues of the most common errors in order to correct the technique of the patient.

> *If you are giving them a written sheet of paper you might give kind of cues around the most common errors that that child might make, in terms of what sort of prompts they might need to help with that quality of movement. And*

> *you'll often say: "sliding across the bed and not lifting" or like you might give kind of instructions on that sheet, as well as then telling the parents and demonstrating to them with the child around what you are expecting. (PT-D)*

In general, physiotherapists go through a session with the patient where parents might even practise facilitating the exercises to their child.

> *We generally have gone though a session with them where the parents might even practise doing it in front of us. So, that we can give feedback to them, we are often watching the child do the exercises while the parent is cueing the child but then the physio might say "Ohh remember in this exercise they need to have their toes pointing to the roof" And you might need to make a note on that on the sheet for the parent to remember that later. (PT-A)*

However, physiotherapists are aware of the challenges for parents understanding the exercises and delivering them correctly. Parents are not experts in physiotherapy, and physiotherapists cannot fully equip parents with the expertise needed.

> *We cannot expect the parent to be able to pick up any sort of incorrect patterns or anything that we would typically look for, but we can facilitate that with the family. We could say "Oh can you see the child is doing this incorrectly, we don't want that to happen". (PT-B)*

The main goals of physiotherapists when educating parents are: helping parents to be able to observe and correct the main common errors of an exercise; providing parents the appropriate prompts in order to correct the child's actions. For example:

> *Sometimes it's not necessary [to] educate them about all of the errors that [the child] might make, but about kind of those main ones that might be more common for that child. (PT-D)*

If required, therapists can also adapt the exercises to suit the family's needs.

> *Depending on the parent they might not necessarily be able to see those and give feedback specific to that pointing time, but I guess we're giving them prompts that would be kind of the most common errors of that child might make, or some things might be a bit easier like: "Kick your leg up to touch my hand", "Oh yeah, you got your leg straight you touch my hand", that's quite an easy one to judge. [...] If it's someone that you think it might not necessarily kind of be able to identify that, you might give them less to kind of think about, or it might be that they do different exercises. (PT-D)*

6.3.3 Parent Engagement

Physiotherapists noted that parents have to actively be engaged in the rehabilitation sessions of their child in order to understand, correct the technique of the exercises, and to motivate their child. Specifically physiotherapists noted that young patients, or patients who do not have the cognitive ability to understand the exercises, strongly depend on the caregivers to facilitate the rehabilitation session.

> *The child might not have the cognitive ability to comprehend [the exercises] themselves. So, therefore, we heavily rely on the caregivers to be the one that facilitates those exercises. However, in other cases where we have got children who have that high level cognitive function and are able to comprehend and take ownership over the exercises, then they can continue [...] without the parent as well. (PT-B)*

> *How well the parent can engage the child also does impact on their ability to perform those exercises, and how they might motivate their child to complete the exercises. (PT-D)*

How parents manage to moderate the session is an important aspect to look for, together with parents correcting the child's technique providing the appropriate prompts when required.

> *I would rate that [the session] is successful based on their handling, but also [exercises done with the] correct technique, along with how engaged the child is. (PT-E)*

> *The parents' ability to cue the child when things aren't going according to plan. (PT-A)*

However, some children can be defensive against parents' prompts, thus a physiotherapist noted that parents should find the way to moderate the session accordingly.

> *And often, you know, the parents prompt some children to complete things and children can be defensive against that as well, which can then be not effective. (PT-D)*

Physiotherapists express the importance of how the session is initiated and framed, explaining how this plays an important role in order to engage young patients. For example framing sessions as a fun activity rather than as a chore, might be more engaging for children.

> *I guess it is probably a lot about how they frame the session to begin with. Like how they, you know, is there a set time where the child knows that they're gonna be expected to do the exercises. And also when it comes to that time is the parent saying: "Okay, now it's time to do your physiotherapy exercises", or they say: "Okay, let's have fun and play some games" and sort of incorporating it into more of a game, rather than exercises. (PT-E)*

Another important role of parents while moderating the session is to be able to identify when an exercise seems to be too hard or too easy for their child, so they can provide feedback to the physiotherapist. If parents are capable enough, they might be able to change the exercise to make it more (progressive) or less (regressive) challenging for their child.

> *[If] The parent says to me: "Ohh this one [exercise] is a bit harder, I just couldn't get into it", then I will still rate it as a very effective that they had a try at doing them (PT-E)*

> *The carers' ability to progress [the exercise] and monitor it. So, to be able to actually make that assessment to see if corrections are needed to be made. [...] If progression is needed to be made because the exercises are becoming too easy or in reverse [...] something like a regression exercise or in some way they can make the exercise less challenging for the child to complete. (PT-B)*

However, if an exercise is too easy or too hard and parents are not able to modify them in order to progress or regress the exercise, physiotherapists note the importance of parents reporting those issues to the physiotherapist.

> *The parent might not necessarily be able to make the exercises harder, but I guess them being able to identify, or flag that it looks easy or a bit easier and what then, you know, to be able to say that back to the therapists, I think is probably the important thing. (PT-D)*

> *I think that feedback is really important from the parents, because if they don't give us that then we can't change the exercises. (PT-E)*

Parents' moderation of the session also includes being flexible with the schedule when doing the exercises. Patients could have had a busy day, so the rehabilitation session, often after hours, should be adapted accordingly.

> *Giving that bit of flexibility in the session because we [physiotherapists] are not going to be there, and we don't know necessarily what sort of day that child might of had, or what might of happened during that day that might impact how they are going to be able to complete the session. (PT-A)*

Physiotherapists noted that parents' engagement and commitment in the rehabilitation sessions is very important in order to engage the child. If parents are not actively engaged in the rehabilitation session, then it is very likely the child is not going to be either. There are different strategies that parents can follow, the most common one is trying to make the session a kind of fun activity, providing cues or goals.

> *Whether it is giving them visual kind of cues or goals, like "kick my hand" and getting involved in that way, whether they can make it into kind of a fun activity. (PT-D)*

> *How the parent is making an engaging session, and the strategies that they are using to make it fun, or you know, to treat it not so much like a therapy session. (PT-E)*

Physiotherapists also provided examples of parents not committed or not engaged during the rehabilitation session of their child.

> *In terms of the opposite, when they are not kind of engaged around, not necessarily participating and not giving them feedback around their performance. Not necessarily giving them kind of an end point to give goals and give that satisfaction of the completion of the task. (PT-D)*

> *That would be the parent not describing it [the exercise] to the child well, not being able to cue the child appropriately, or not engaging the child. (PT-A)*

Parent's communication and interaction with their child can also be a sign of parent engagement.

> *The interaction between the parent and the child. And you know, how the parent is making an engaging session, and the strategies that they are using to make it fun, or you know, to treat it not so much like a therapy session. (PT-E)*

Framing sessions as fun activities does not always work. Therapists note that parents often use other strategies such as rewards in order to entice their child to comply in the rehabilitation session.

> *Positive reinforcement and using rewards [are] strategies that often parents would use. If they have a reward at the end of completing the exercises, particularly in a hospital setting, it can be a treat after the session. Something like bribery, so that's probably one of the most common strategies that parents*

> *use. [...] It could be that they go to the park after they do their exercises, or they get to play a computer game, or something that's important to the child that they then use as a way to encourage them to do the exercise programme. (PT-B)*

Bribery could be in the form of a sticky chart, collecting stickers.

> *When you get a certain amount of stickers then you get to choose a toy or whatever. (PT-E)*

Also the inclusion of other family members coming to the session of their child, such as parents, siblings or grandparents helps to engage the child.

> *Participation by the parent in the activity, or getting another family member involved as well often is helpful (PT-A)*

While having family members might help the child to do the exercises, physiotherapists also note that having too many people in the room might cause distraction. It is important that patients are focused on the task ahead, and all possible distractions are removed.

> *[Remove] all other distractions in the room, [which] depends on type of patients. Like if it is a patient with a brain injury, I would be always encouraging less distractions. So, that they can focus just on the task ahead. [...] Distracted for example by TV, iPad, too many people in the room... (PT-E)*

In the hospital setting, parents are often asked to run sessions each day on the ward, however, physiotherapists find that rehabilitation exercises are often not done.

> *We're asking parents to [run sessions with their child] twice a day, we would usually say do it morning and afternoon. But, we wouldn't necessarily specify do it at this time, we just say fit it in to your day depending on what you're doing. But, I think probably what we find more often than not is that [rehabilitation exercises] would not get done more than it would get done. (PT-E)*

There are different reasons why the exercises are not being done. Time constraints, children not interested, or parents not confident enough with the exercises are some of the reasons for not doing the exercises on the ward. For example:

> *[not completing the exercises] because of the parent's ability to complete the exercises, because of time constraints, because of lack of understanding of the programme or because the kid is not interested. (PT-D)*

Other reasons for not completing are parents seeing the weekend as a break from therapy, or not worth the trouble of running the session.

> *Maybe they see the weekend as a bit of a break from therapy. There is probably a lot of parents who have other children either at the hospital or at home they're looking after. [...] I guess it is not feasible for it to be done. Some parents I guess feel that it is not worth the hassle trying to get the patient, the kid, to do it if it's something that they're seeing more as exercises rather than as a game. (PT-E)*

Physiotherapists also mentioned that parents might not be confident to run sessions because of the lack of understanding of the exercises.

> *And I guess the other thing might be some parents don't feel confident or perhaps don't understand the exercises but maybe don't speak up about that. [...] one other thing is often parents can be sort of swapping over care on a weekend or something. So, if we are seeing a patient during the week and mums are constantly coming to the physio sessions when we run though the exercises programme with mum, and then dad looks after them on the weekend, I guess there is things like: has mum had a chance to go through the exercises with dad? Did mum understand well enough to be able teach them to dad? Does dad then feel confident doing it without instructions from a physio? (PT-E)*

Other reasons for not completing the exercises are related to the engagement of the child.

6.3.4 Patient Engagement

Parents can try their best in order to moderate and engage their child, however, it is not always successful. This is the next theme extracted from the interviews. Physiotherapists rated it as very important that patients are actively engaged in completing their exercises. For example:

> *The child is able to get through the programme focused on the task without being distracted by others activities. (PT-E)*

Another physiotherapist mentioned the child being able to go though the programme without being too needy.

> *[The patient] To be actively participating, not needing a cue every 2 seconds to complete the exercise, and getting through at least that minimum sort of expectation of what we wanna complete in that session. (PT-A)*

And patients should be actively participating in their exercises:

> *[...] and sort of participating and being more an active participant rather that just laying there and expecting the parent to do it for them. (PT-A)*

If patients have sufficient cognitive function to comprehend the exercises, they should take ownership over the rehabilitation programme and depend less on their parents. Doing rehabilitation independently is a good sign of engagement for cognitively able patients.

> *We have got children who have that high level cognitive function and they are able to comprehend and take ownership over the exercises, then they can continue [without a supervising parent] [...] So, I think a lot of it depends on where the child is cognitively and, intellectually how they can comprehend instructions and then translate that into physical performance of the exercises. (PT-B)*

Patients are prescribed the same exercises to complete on-ward as they do in sessions with a physiotherapist. If cognitively able, physiotherapists often expect they should be able to remember how to do the exercises.

> *We will give [the child exercises to complete alone] that we have done within sessions, so the child should be aware of kind of how to complete them. (PT-D)*

Patients engaged in their rehabilitation sessions are an important source of information for therapists about the patient's progress in doing the exercises on-ward.

> *Often the child says "Ohh mum does it much too quickly" or you know "Dad does this, and I don't think that's right!" [..] depending on the child they can tell you a lot. [..] some people always say their mum is too mean, or some people always make one specific comment, whereas some kids can be quite honest about how the session has gone. (PT-A)*

Patients who are not engaged in their rehabilitation exercises can express that with negative comments, or with their interaction with their parents.

> *[Another way to identify if patients are engaged is] the communication between the parent and the child. So, if the child is not speaking, or if they are speaking but saying: "I don't wanna do this", or "Ohh, how many more to*

> *go...", or "Ohh, can we stop now?". So, yes, the different child's communication between the child and the parents, whether it is sort of positive interaction or becomes across something a bit more of a negative interaction. (PT-E)*

Different patients often require different strategies of engagement. The age of the patients is an important factor to consider when trying to engage them in their rehabilitation. Making the rehabilitation sessions as a fun activity might be useful to engage young patients or children.

> *If it was like a 5 year old [...] I would suggest the family find a game that the child likes, and play it on the couch in the room, and have them kneeling down on the floor, we usually provide them with a mat. (PT-E)*

Whereas for teenagers or adolescents, understanding the importance of their rehabilitation programme is a more useful strategy of engagement.

> *As they get older, if it was a teenager then [...] you are not gonna trick them into thinking it's a game, they might be at the maturity level where they actually just know that it's an important part of their rehab, and they have to actually just do their exercises. (PT-E)*

Adolescents should also become more independent and not require their parents.

> *When they're getting more towards adulthood it is not so much about the interaction between mum and dad, it is more about the child taking some ownership and becoming independent with the programme. (PT-E)*

There are different reasons for not completing the exercises. For example, time constraints:

> *Time is probably one of the biggest barriers we [hear from parents] [...] among the other daily routines participation in extra-curricular activities, school, daily life activities. It's just time, the common question we generally get is: "I don't have time to compete the exercises", or "I can't fit it in to my day". (PT-B)*

Lack of patient compliance is another reason for not completing the exercises:

> *That's probably one, the second one is compliance. We would generally get families who are very keen to have an exercise programme, but they just can't get their child to complete by actually perform the exercises because of lack of compliance and cooperation on the child's behalf. (PT-B)*

Lack of interest on the child's part.

> *Interest on the child's part. They are just not into doing any physical activity, they're quite sedentary or, their interest might be non-physically related activities. (PT-B)*

And also lack of child's concentration and fatigue. Therefore, some physiotherapists might set a minimum number of exercises to be completed per day, allowing for more in case patients have time and the stamina to complete them.

> *Kids concentration, and then level of fatigue can change on different days. So, we often sort of say: "This is what we want, as a minimum to complete, and if you have got time, or if you are feeling good, do this" (PT-A)*

Patients who have spent long periods of time in the hospital might have had enough, are exhausted, and tired of the rehabilitation. Those patients might start playing up more for their parents and not do their exercises prescribed.

> *Often [patient's engagement] is that relationship between the parent and the child, particularly when they are inpatients in the hospital, and depending how long they have been with us. Often the kids just over it. And we've sort of lost them, and they will do it for the therapists because it is a bit of a different relationship. Often we see kids who have been in hospital longer, they start playing up for their parent more, and I think that's where it gets harder on the parent. And the parents wanna do the right thing, and they wanna do what you are asking to do but it's just really challenging for them to engage their child. (PT-A)*

6.3.5 Robot Presence

Participants in these post-study interviews are therapists who participated in the previous study and have used the robot in some of their rehabilitation sessions. The effect of the robot's presence was the last derived theme from the interviews with physiotherapists, in which they reported how the robot affects the dynamics of the session based on their experience in the previous study.

Physiotherapists indicated that with the robot present in the rehabilitation session they will look for much the same things to evaluate the success of the session.

> *I think to me it would be... It's essentially the same. It's the same criteria because you have kind of got the robot as your sort of demonstrator and*

> *something for the child to hopefully engage them slightly more. But, in terms of what the parents role in the parents session, and how that worked I think it's very similar. (PT-A)*

> *with Rosie [the robot] present, to be honest, it will be pretty much the same. (PT-B)*

Physiotherapists did indicate that if the robot is in the session, it might require less effort for the parent to engage the child.

> *Having Rosie probably doesn't require as much parent engagement. Obviously, most of the kids would still need the parent to set up the robot. But, I guess the robot is acting as the thing that's hopefully going to keep the child engaged rather than requiring that from the parent. (PT-E)*

Apart from the robot assisting with engagement, physiotherapists indicated the robot can also help parents understand the exercises to be done.

> *I think the engagement [with the exercises] is probably the one thing that I think Rosie definitely assists with, and potentially in terms of parents' understanding of the exercises, it may also be less difficult with Rosie, in terms of having a moving visual representation of the exercises in comparison to an illustrated version that kind of may show the different steps of the task. (PT-D)*

Physiotherapists noted that the companion role of the robot is another aspect which assists parents with the correct performance of the exercises.

> *The robot dictates the speed of the session and does the exercise itself. And, so I think for a parent, that can be quite nice, because they then do not have to judge, how long was that? Are they [patients] doing it too fast? Are they doing it to slow? (PT-A)*

While the interviewed physiotherapists acknowledged that the robot helps parents engage their child and understand the exercises, it was also noted that parents still have to be engaged in order to identify errors, provide prompts accordingly, and moderate the session.

> *Rosie is the demonstrator of the session who I guess directs what exercises are going to be completed, and provides the instructions for them. However, I would still see the parent as the one that's able to correct, whether by means of physically repositioning the child, or giving the child feedback. (PT-B)*

> *You still need, at some level, parent engagement to be correcting technique, but it is not so much about perhaps the verbal communication. It's probably more about the parent being the supervisor of the session and just how to manage things that are going wrong. (PT-E)*

Following this line of thinking, one therapist gave an example of how the parent can moderate the session if the child gets tired after a few repetitions and loses the technique.

> *There is still enough control for the parents to be able to say: "Okay you meant to get to 10 but you really lost your technique at 8, let's just watch the robot do the last 2" (PT-A)*

Physiotherapists noted that the robot provides good generic prompts to correct the patients' technique during the session, which helps parents to run the session and remind them of the correct technique of each exercise. However, a number of physiotherapists stress that parents should still provide more specific or visual prompts to their child as well.

> *The good thing [of having the robot] is the robot then does remind the cue [for each exercise]. [...] And so when [the robot] provides that sort of general cueing the parents are: "Ohh that's what I need to be checking for". Because I think it is hard and we do expect a lot of the parents to do. Because we are therapists and they are not trained in that way. (PT-A)*

> *Rosie gives some really good kind of general errors and general prompts, and I think that kind of takes away some of that kind of responsibility [from the parent], but I guess there may be other prompts that might work better for some children, or might be that they need kind of that visual prompt [as well] around. Something like "lift you hand up", or "kick your leg up to touch my hand". (PT-D)*

Physiotherapists noted that parents generally follow the robots' instructions for the session, so that helps to take away some of parents' burden reminding them the exercisers, repetitions, or the speed.

> *They don't necessarily have to remember the speed, and the counts, and things as much because that's kind of pre-programmed. So, it's a bit less for them to remember in that sense. (PT-A)*

A therapist noted that having the robot in the session can also have negative aspects, such as introducing time pressures.

> *With Rosie there might be more time pressures. Because I guess Rosie is programmed to complete a certain amount of exercises in a specific time frame, you don't have as much adaptability that can happen at the time. [...] The parent doesn't have that control over how fast or how slow Rosie is going. (PT-B)*

Parents providing feedback to the physiotherapist is again an important aspect about the parent's engagement. Physiotherapists need to know how the session went with the robot in order to fix what is not working properly during the session.

> *For example if they did a session with Rosie today, and then they come back and report it to myself that the exercises were too fast or too slow. Then, we would then have to reprogramme Rosie in that aspect. (PT-B)*

6.4 Derived Observable Indicators for Evaluating SAR-Assisted Care Delivery

Section 6.3 presented the themes extracted from the interviews to the physiotherapists when asking how they would evaluate the success of a rehabilitation session delivered by a carer via observations. This section presents the list of observable items derived from the themes and the codes of the interviews. The list presented in this section is composed of observable items to evaluate the success of a rehabilitation session delivered by a carer with the help of a SAR. From each of the themes (represented also in a thematic map in Figure 6.2) a list of observable items has been derived from the codes and sub-themes.

From all the items presented in this section, an Objective Structured Assessment Form (Appendix C.5) has been derived in order to evaluate how well a robot integrates when in daily use in an on-ward hospital setting without physiotherapist supervision. This evaluation instrument will then be applied in Phase 3 of this study, described in Chapter 7

6.4.1 Carers Engagement

The way parents frame and initiate the session can be indicative of carers' engagement in the session. Carers are responsible for removing all the distractions that can affect the child's concentration. Providing prompts, or correcting patients' technique are also tasks carers should be doing during the rehabilitation session. However, those tasks also require the parent's understanding the exercises, thus, the items are included in the next category: Carers Understanding and Engagement.

Initiation and Framing of the Session

The initiation of the session, or how the rehabilitation session is framed plays an important role in order to engage young patients. For example, if the rehabilitation exercises are framed as a chore, or as a boring task to do rather than as a game, carers might find more difficulties when trying to engage the child in the prescribed programme. Some families might also frame the rehabilitation as an important task of their child's recovery.

Below lists the observable items derived from the interviews. Note that the observation form also allows any other observable items to be added by the assessor.

Carer's attitude before starting the rehabilitation session:

- Positive attitude.
- Positive attitude, using the robot as a motivator.
- Positive attitude, including some sort of bribery/rewards to motivate the child.
- Important part of the recovery.
- Chore.
- Other, please indicate.

How is the session framed:

- Like a game.
- As an important part of the recovery.
- Chore.
- Other, please indicate.

Distractions

Patients should be focused on the task ahead. Carers should make sure there are no distractions in the room that can take patients' attention away from the rehabilitation.

Below is list of most common distractions in rehabilitation sessions as indicated by the therapists.

Are there any distractions in the room?

- TV.
- Phone/Tablet.
- People (busy room, etc.).
- Disengagement.
- No distractions.
- Other, please indicate.

6.4.2 Carers Understanding

If patients do not have the cognitive ability to understand the exercises, they heavily depend on their parents/carers in order to do the exercises. Carers not only have to be engaged, they also need to have an understanding around the goals of the exercises. Understanding categories comes very close to engagement, understanding cannot be evaluated without the carer being engaged.

Robot Demonstration

The robot demonstration informs the carer of the exercise to be done, helps carers to remember important aspects of the exercise and the correct technique. However, experienced carers who are already familiar with their child's rehabilitation programme might not need to follow the robot's demonstration.

During the robot demonstration:

- The carer uses the robot demonstration to explain the exercise to the child.
- The carer reminds the child the exercise to do.
- The carer gets distracted and misses the demonstration, but knows how to continue.
- The carer gets distracted, the robot is flashing and they don't know what to do next.
- The carer ignores the robot.
- Other, please indicate.

Carer Involvement in the Session

Carers should be actively involved in the rehabilitation of their child in order to gauge errors, or assist their child when required.

During each exercise:

- The carer is observing and helping assisting robot/child.
- The carer is observing closer to the patient.
- The carer is observing from a distance.
- The carer is distracted with other things (phone, talking, etc.).
- The carer is not paying attention to the patient.
- Other, please indicate.

Carer Providing Prompts

It is important that carers provide the appropriate prompts in order to correct the child's technique. The robot provides reminder cues, however, carers can provide more specific cues that will work better for their child. Some patients can be defensive towards carers' prompts, so carers should adapt accordingly to their child's situation.

Prompts

- The carer uses prompts from the robot to correct their child technique.
- The carer corrects posture/technique (hands on patient).
- The carer uses prompts from the robot to encourage their child.
- The carer provides verbal and visual prompts / indications (e.g., touch my hand).
- The carer provides encouraging statements.
- The carer provides verbal prompts / indications.
- No prompts.
- Other, please indicate.

Session Moderation

How carers are able to moderate the session is an important aspect in the rehabilitation sessions. For instance, parents can be moderating the session progressing the exercises if they are perceived too easy, or letting the child to not finish the last repetitions due to exhaustion.

Moderating

- The carer gives the patient that satisfaction of completion of the task.
- The carer makes the exercise harder/easier (progression/regression).
- The carer lets the child to not finish the exercises due to exhaustion/losing technique.
- The carer provides/mentions rewards/bribery to engage the child.
- The carer asks the child to beat the robot (compete with the robot).
- Other, please indicate.

6.4.3 Patient Engagement

Patients taking ownership of the exercises is a good indicator of their engagement or emotional maturity. However, some patients might not have the cognitive ability to comprehend the exercises, so need the help of an adult to go though their rehabilitation programme. The engagement of a child in the rehabilitation session can be measured by their attitude, their compliance with the prescribed programme, and their interaction with the facilitator or the robot.

Robot Demonstration

The robot demonstrates the exercise to be performed. Patients watching the robot while it demonstrates the exercise is a good indicator of patient engagement. However, some patients might already be familiar with the exercise, and this might reduce the need to pay attention to the robot. Thus, items for patients already knowing the exercise, or how to continue the session are also provided.

During the robot demonstration:

- The patient pays attention to the robot demonstration.
- The patient reminds the parent the exercise to do.
- The patient gets distracted and misses the demonstration, but knows how to continue.
- The patient gets distracted, the robot is flashing and they don’t know what to do next.
- The patient ignores the robot.
- Other, please indicate.

Attitude

Other measures of engagement in the rehabilitation session are related to the child’s attitude with the caregiver or the robot. Patients can be more interested in the robot and not pay enough attention to the caregiver, or vice versa.

With the robot during the exercises

- The patient is willing to interact with the robot via verbal communication.
- The patient is willing to interact with the robot by helping/assisting.
- The patient is willing to interact with the robot by tapping its head.
- The patient follows the robot instructions.
- The patient ignores the robot.
- The patient dislikes the robot (negative comments or facial expressions).
- The patient dislikes the robot and yells at it.
- The patient dislikes the robot and the session has to be aborted.
- Other, please indicate.

With the caregiver during the exercises

- The patient follows the instructions of the facilitator.
- The patient and the facilitator talk during the session.
- The patient asks the facilitator to be quiet because they want to listen to the robot.
- The patient asks the facilitator to be quiet.
- The patient argues with the facilitator.

- The patient gets angry to the facilitator.
- Other, please indicate.

Feedback

Patients providing feedback about the exercises is an important aspect in order to adjust the rehabilitation to optimally fit the patient's needs. Exercises that are too easy should be progressed, or if too difficult, regressed. Patients complaining about the exercises because they do not want to do them is an indicator of reduced patient engagement in the session. However, this may be due to a range of factors, e.g., fatigue, discomfort, motivation.

During the exercise - Feedback

- The patient finds and mentions that the exercise is easy.
- The patient finds and mentions that the exercise is hard.
- The patient complains about the exercise (Pain, etc.).
- The patient dislikes the exercise (Negative comments).
- The patient is just not interested in the exercise.
- The patient complains about the instructions/cues provided by the robot.
- The patient complains about the instructions/cues provided by the facilitator.
- Other, please indicate.

Completing Exercises

There are different reasons why the exercises are partially completed, or not completed in the rehabilitation sessions. While exhaustion might indicate that the patient has had a busy day or has been working intensively in the rehabilitation session, distractions, disengagement, or bad behaviour might indicate a lack of engagement of the child.

During the exercise - Completing Exercises

1. The patient refuses to do or try to do an exercise.
2. The patient refuses to finish an exercise (e.g. a set).
3. The patient does the exercise with a very bad performance or not interested.
4. The patient easily gets distracted and/or misses some repetitions.
5. The patient does all the sets of exercises chosen by the physiotherapist.

Reasons for not completing

- Exhaustion.
- Pain.
- Behaviour.

- Distractions.
- Disengaged.
- Other, please indicate.

6.4.4 Technique

Therapists mentioned the speed, the use of compensatory muscles, or bad postures as things that they would look for in order to evaluate the technique. Trained therapists with experience in rehabilitation are the most appropriate to evaluate the correct technique of the exercise. Therefore, this theme has not been included in the Objective Structured Assessment Form, which is intended to be used by researchers without training in physiotherapy to evaluate the integration of the SAR when in daily use in an on-ward hospital setting. This theme, thus, it is expected to be evaluated only by a trained therapist during Phase 3. For completeness, however, the observable items extracted from the interviews are listed here:

1. No effective exercise due to using compensatory muscles/speed/positions.
2. Sometimes using compensatory muscles/incorrect speed/bad positions.
3. Sometimes using compensatory muscles/incorrect speed/bad positions. Carers identify and cue the child.
4. Good technique (not using compensatory muscles, good speed, positions).

6.5 Limitations

The small number of participants is a limitation in these post-Phase 2 study interviews. Participants were selected from those 8 therapists who participated in the previous study and were available to participate. This study, however required physiotherapists who were already familiar with the hospital environment in order to derive the metrics for the next study of the thesis: how the robot integrates in rehabilitation sessions on the ward. This study also needed participants who had previously operated the robot to comprehend the impact of the robot in the rehabilitation sessions.

This study recruited physiotherapists from the same city-based busy hospital. Responses from the participants may therefore not always be applicable to other hospitals and other health care settings with different characteristics, such as regional or rural hospitals

While the facilitator of the interviews was not known by the interviewees, the author of the thesis was known by the physiotherapists from the previous Phase 2 study. There is no evidence participants provided positive responses due to this relationship with the researcher. In fact, therapists were very open to talk about negative aspects of the SAR based on their last experience.

Another limitation of this study is the lack of visual cues during the phone interviews. Doing the interviews over the phone was necessary due to scheduling constraints, however, phone interviews may have limited the extent of contextual and non-verbal data captured [163].

6.6 Summary

This chapter has presented post-Phase 2 study interviews with physiotherapists to define an evaluation method for the success of a rehabilitation session delivered by a carer with the help of the robot, and to evaluate the impact of the robot in therapy delivery. Four of the eight therapists who participated in the Phase 2 study were available to take part in the interviews.

From the interviews a list of observable items has been derived in order to evaluate, via observations, the success of a rehabilitation session. This evaluation method will be used in the next study (Chapter 7) to evaluate how the robot integrates and performs when in daily use in an on-ward hospital setting without physiotherapists supervision, but under the supervision of an adult carer. This is in line with the identified primary use-case of the SAR in this thesis.

This chapter has also explored the impact of the developed SAR on therapy delivery as perceived by therapists after extensive experience with the SAR. In general, therapists report that the robot has a positive impact on the rehabilitation sessions if there are no system disruptions, and if therapists feel confident enough to use it. Proper training to caregivers can reduce the negative impact of the robot in rehabilitation. Caregivers aware of the capabilities and expectations of the robot can reduce their nervousness and/or frustrations.

System disruptions can have a very negative impact if therapists cannot recover the rehabilitation session in a timely manner. System errors can affect negatively the patient's mood, and frustrate therapists when trying to fix technical issues. This emphasises that while in situ testing is informative, it can also negatively impact trust, and thus should not replace robust software engineering practices.

The next chapter presents Phase 3 of this study. In this chapter, 1 pilot and 3 case studies of parents delivering rehabilitation sessions with the help of the robot are presented. These case studies occurred over a week in order to explore how the SAR performed and integrated in an on-ward setting.

Chapter 7

Socially Assistive Robot Integration in an On-ward Hospital Setting

Previously, in Phase 2 of our design process and evaluation methodology, I evaluated the acceptance of the Socially Assistive Robot (SAR) prototype for in-clinic use (Chapter 5). Results included broad acceptance of the prototype SAR, with near universal agreement that the SAR was useful, and easy to use by therapists and parents. Particularly, young patients responded overwhelmingly positively to the SAR's inclusion in their rehabilitation sessions. With iterative improvements from Phase 2 implemented, I now consider the SAR's integration into daily use in an on-ward hospital setting in accordance with Phase 3 of the design process.

Preparations for this phase began in Chapter 6, where I derived observable items for an Objective Clinical Assessment to assess the quality of care delivery with the SAR without physiotherapist supervision. These items were extracted from a thematic analysis of physiotherapist interview transcriptions.

In this chapter I apply present Phase 3 of the study, consisting of one pilot and three case studies to evaluate the integration of the SAR in the hospital ward when in daily use with inpatients. As previously explained in Section 4.1.8, the robot currently integrates a tablet based interface to configure rehabilitation sessions into the robotic system, and to execute them. In the case studies presented in this chapter, parents are asked to use the robot by themselves, on the ward, without therapist or technical supervision.

Through this, this chapter makes the following novel contributions:

- The first on-evaluation of a social robot for rehabilitation as part of regular on-ward clinical care, over multiple days to individual patients.
- New insights into the integration of SARs in an on-ward setting.
- Key learnings for researchers regarding practical issues for running in situ studies in a busy on-ward hospital setting.
- Design and deployment considerations for the integration of novel new technologies, such as SARs, in clinical on-ward settings.

This chapter is structured as follows. The pilot study which guided the design of the case studies is presented in Section 7.1. Section 7.2 presents the method followed in the three case studies where parents use the robot to deliver therapy sessions during a week long period of care. The three case studies of parents delivering daily rehabilitation on the ward are presented in Section 7.3, Section 7.4, and Section 7.5. Section 7.6 presents a critique of the Objective Clinical Assessment form used in the case studies. The limitations of the studies carried out in this chapter are reported in Section 7.7. Finally, a summary of the chapter and broader implications are presented in Section 7.8.

7.1 Pilot Study

An initial pilot study took place before the derivation of observable items from physiotherapist interviews presented in Chapter 6. I therefore consider the pilot study separately, and discuss how findings informed the case-study design presented later in this chapter.

Figure 7.1 shows the timeline representing the different time frames of Phase 3 studies: the pilot study reported in this section, the interviews to physiotherapists discussed in the previous chapter, and the 3 case studies presented in Sections 7.2 through 7.6.

Figure 7.1: Timeline of Phase 3: pilot study, interviews, and case studies.

7.1.1 Method

This subsection presents the trial environment, the participants' recruitment, and the procedure of the pilot study.

Patient Recruitment

Ethics committee approval was obtained from both partner institutions: The Royal Children's Hospital Melbourne Human Research Ethics Committee (HREC 36128C) and Swinburne's Human Research Ethics Committee (SUHREC Project No: 2016/202). Ethic clearance is provided in Appendix B.

An inpatient with cerebral palsy undergoing intensive therapy was recruited to participate in this pilot study based on: the availability of the family, the patient having a rehabilitation programme consistent with exercises implemented in the SAR, and physiotherapists' clinical judgement. Informed consent was obtained from the parents of the patient on behalf of themselves and their child. Table 7.1 provides an overview of the patient's condition, which parent operated the robot each session, and places where the rehabilitation took place.

Table 7.1: Pilot study participants.

No	Gender	Age	Diagnosis	Rehab Reason	Session	Place	Parent
F-1	Female	5	CP GMFCS III	Functional rehab (intensive therapy)	1	Gym	Mother
					2	Treatment room	Mother
					3	Treatment room	Mother
					4	Treatment room	Mother
					5	Patient's room	Father

Trial Environment

The pilot study made use of several spaces within the hospital throughout the week-long evaluation. Spaces included the gym which is a big open area for rehabilitation; small treatment rooms; and also in the patient's room. Figure 7.2 shows the hospital rooms used in this pilot study.

The first session (Day 1) started on a Tuesday and was done in the gym, due to external distractions affecting the patient's concentration (such as other patients or staff interested in the robot), the location was changed for the next sessions. Day 2-4 sessions (Wednesday to Friday) were conducted in a small treatment room on the ward. The room was a quiet and a suitable place to run sessions with the robot, however, those rooms required booking and thus not always available. Day 5 (Monday) parents were unavailable to participate, so the last session was completed in the patient's room due to unavailability of the treatment room.

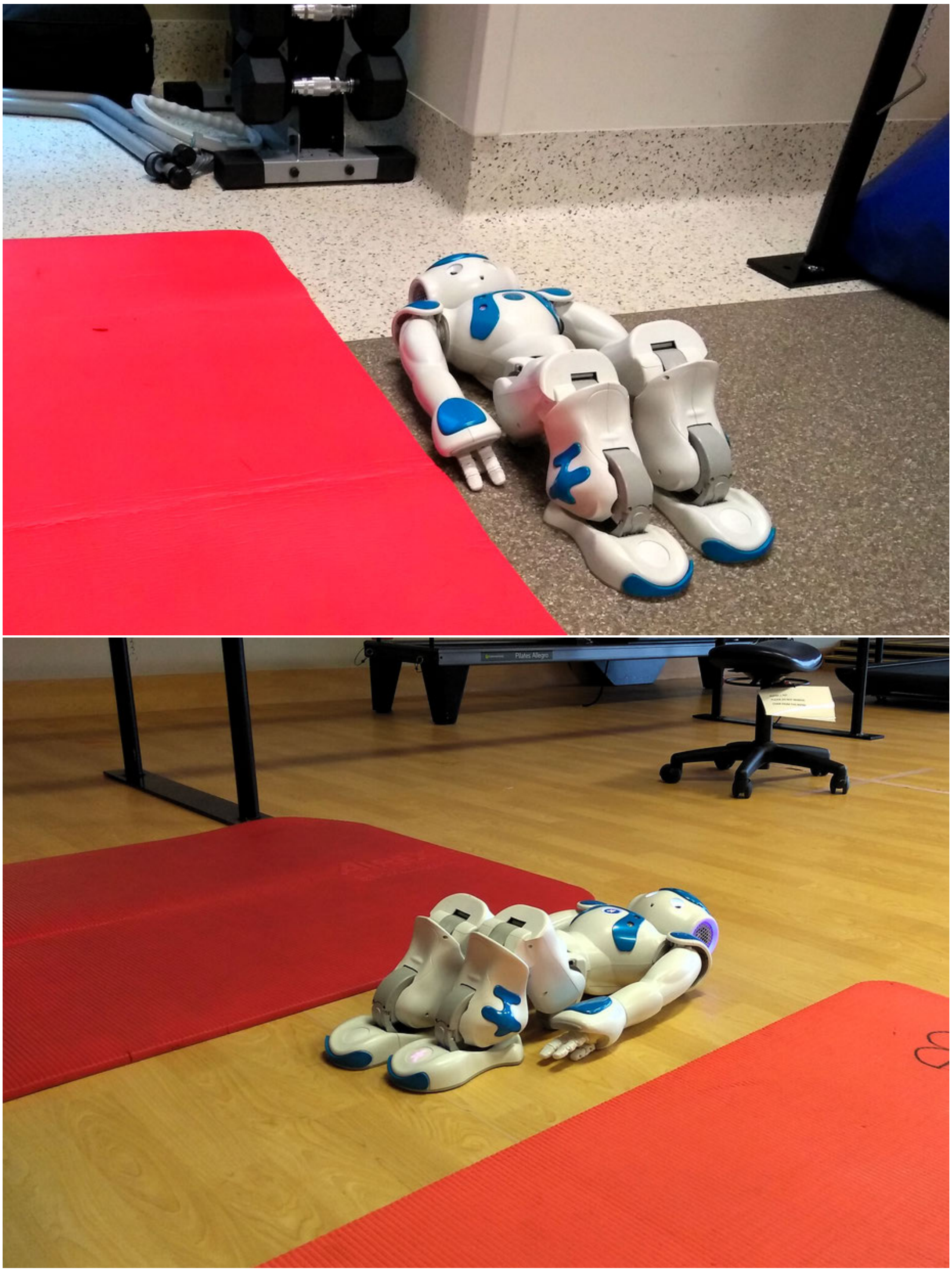


Figure 7.2: Pilot study setting. Upper image: the NAO robot in the treatment room with a mat for the patient. Lower image: the NAO robot in the gym.

Study Procedure

Inpatients with cerebral palsy undergoing rehabilitation after surgery, typically stay 2 weeks hospitalised in the rehabilitation department of the hospital. In this study I aimed to test the robot in daily use as part of the patient's prescribed rehabilitation programme. One week was considered a practical duration, providing flexibility for the study, and not too disruptive to the patient's other commitments in the hospital. Weekends were excluded due to complications regarding storage of the robot and availability of the personnel.

As concluded in previous chapters, training inexperienced users to operate the robot plays a crucial role in users' confidence, reducing users' anxiety, and to decrease the number of system errors. Incorporating this finding, I planned the pilot as follows:

Session 1: the treating physiotherapist of the child delivers therapy using the robot as done in Phase 2 study (Chapter 5). The parent in charge attends, and observes the session. The research engineer attends to assist with the robotic system if required.

Session 2: the research engineer (author of this thesis) explains to the parent the basic steps to set-up the system. The parent in charge delivers the rehabilitation session as done in Phase 2 study. The research engineer and the therapist observe the session from outside the room, and are available to help if required.

Remaining Sessions: the parent in charge sets-up the robot and delivers therapy with the robot *without therapist or engineer assistance*. Sessions are observed from outside the room.

Sessions were configured using the tablet interface (Section 4.1.8) and saved into the system beforehand by the treating physiotherapist. The NAO robot used during Phase 3 studies was a different robot from Phase 2, but with the same characteristics: blue teal NAO version 4. Similarly to the Phase 2 study, rehabilitation sessions run without any backup support such as a second robot, a second laptop, alternative access point, or a battery replacement.

The set-up of the system consists of switching on the NAO robot and the server (running on a laptop next to the robot). The server is already configured to establish a Wi-Fi hotspot in which the robot automatically connects. Once the server detects the NAO robot connected to the Wi-Fi hotspot, right before the audible cue “OGNAK GNOUK”, the server will automatically start all the required ROS nodes (two ROS launch, `nao_bringup` and `nao_sm_rch` as explained in Section 3.2). The SAR will express its readiness via the visual cue described in Figure 3.7c of Subsection 3.3.6. The attending carer, either therapist or parent, is then required to select from the tablet interface the corresponding rehabilitation session for the day.

Once the robot receives the rehabilitation programme, it indicates again its readiness by saying *“I am going to wait until some one taps my head”* and with the visual cue as described in Figure 3.7a. Participants then start the rehabilitation session by tapping the robot’s head. The robot then runs the session as described in Section 3.2.2.

7.1.2 Pilot Results

Data was collected via observations collected by myself as the attending research engineer regarding participants’ interactions with the robot, system disruptions, technical issues, and participants’ reactions to those issues.

Four emerging themes were noted from the observational data collected during this pilot study: patient focus, impact of environment, methodological flaws, and practical challenges of daily use. Themes are detailed below.

Patient Focus

The first session was carried out in the gym because it is a spacious place and able to accommodate the patient, the attending parent, the treating physiotherapist, and two observing researchers (a physiotherapist and myself). However, it was observed that other activities which took place at the gym affected the patient’s concentration during the session. This was confirmed by the attending parent at the end of the session, mentioning that with less people around, the patient is often more compliant with the exercises. As such, the following session was carried out in a small treatment room in order to reduce the number of distractions. However, even the presence of researchers was observed to alter the patient’s concentration and focus.

During the design of the SAR, it was considered important to build rapport with the patient and the robot at the beginning of the session (Section 3.2.2). We also considered important the robot demonstrate the exercises indicating key aspects before starting a set (Section 3.1.7). However, it was observed in this pilot study that the patient was not interested in the robot’s introductory speech or in the demonstration of the exercises. Conversely, it seemed that instructions delivered by the robot had a negative impact on patient’s focus, so introductory speeches were removed for the next sessions. Exercise demonstration were also observed to cause a loss of focus in later sessions due to the patient already knowing the exercise being demonstrated. In the Day 3 and 4 (Thursday and Friday) rehabilitation sessions, the parent kept the child focused during the system set-up and during the demonstration of the exercises by incorporating other elements into the rehabilitation session such as cards with drawings.

This indicates that the SAR adaptability to different patient needs is even more important over multi-day sessions. This is in contrast to Phase 2 where these issues did not arise due to low number of sessions per patient and frequency.

Impact of Environment

Delivering daily rehabilitation sessions over a week in the hospital environment brought new challenges not experienced in the previous Phase of the SAR's evaluation.

Sessions were run in three different locations, with the change of locations causing some problems with the logistics of the pilot study. The first day in the gym, the robot was placed on a soft surface. Due to the lack of a table or a proper surface to place the robot, the robot lost stability when changing position and engineer assistance was required. In further sessions of the pilot study, no more engineer assistance was required after the set-up of the robot. Missing furniture also impacted the second session in the treatment room. A small chair for the patient was missing, causing problems for the sit-to-stand exercise. Due to the unavailability of the treatment room, the last day session was run in the patient's room. Of all the locations tested in the pilot, the patient's room was observed to be the most appropriate location to conduct the SAR testing. Only staff members can book treatment rooms on the ward, thus parents can only run rehabilitation sessions independently in the patient's room.

Methodological Observations

A challenge faced in this pilot study was the presence of researchers and their impact on sessions. The treatment room has a small window to the corridor from which observations were taken. The presence of researchers was observed to divert the patient's focus from the rehabilitation session to the window. It was also felt that the independence of parents when operating the robot was compromised when researchers were obviously present and observing. For example, the robot was tilted by the parent in the middle of the third session when standing up, so the robot's inbuilt fall manager was invoked, causing it to unstiffen all motors. While the parent had been informed how to recover the robot by themself (due to the implementation of this feature in V.0.13.0), the parent left the room in the next session (fourth session) and asked researchers for assistance to move the robot due to being afraid of the robot falling. This suggests that the known presence of researchers could be an impediment to properly evaluate the robot integration on the ward. In addition, this also suggests parents should be asked about their anxiety levels when using the robot independently. While our presence might have impacted participants' behaviour during the pilot study, we argue that those observations are still valid for the design of the case studies, but necessarily limited in what can be concluded with regards to the SAR's effectiveness. As a result of those observations, changes to the study were made as summarised in Table 7.2. Participants will operate the robot independently without the presence of researchers during at least 2 days. We consider that it will be still valuable to observe the last session at the end of each case study to evaluate the prototype integration on the ward.

In Chapter 6, physiotherapist interviews highlighted that other activities happening on the ward can effect the patients' mood during their rehabilitation session. The parent noted during the debriefing after Friday's session that the patient was a bit bored because there was another interesting activity for her happening on the ward such as cooking.

The intention of these case studies was to run all the rehabilitation sessions with the same parent. However, this was no possible in the pilot trial. In general, parents often alternate the care of their child with their other commitments outside the hospital. In the pilot study, the first 4 sessions were delivered by the patient's mother, and the last by the father. The last session had to be rescheduled to the next day (from Monday to Tuesday) due the patient's other commitments with the hospital. Thus, the last session was delivered by the father, who operated the robot for the first time. While the father showed competence using the robot to deliver the rehabilitation session, this highlighted another methodological challenge for Phase 3, and in general, for such in situ evaluations.

System Issues and Improvements

Observations from the Phase 3 pilot resulted in some system adjustments from Phase 2. As previously mentioned, exercise demonstrations were observed to be tedious when the patient already knew the exercise, thus, the system should be improved to allow users to skip exercises demonstrations. Another need for system improvement related to the sit-to-stand exercise was identified. While this activity is one of the most interactive between patient and robot due to the required number of head taps (to stand up and to sit down the robot), it was observed that the complexity when delivering this exercise is harder if the patient is not independent enough. For instance, in the sessions, the parent held the patient with one hand while standing up, and then tapped the robot's head with the other hand. This happened because either the child was unable to do it, or because the parent was too worried about the robot falling. The prototype could include another sit-to-stand exercise based on timing. The patient or carer will need to tap the robot's head to stand up, and then the robot will sit-down after a configured time, as set by child's the physiotherapist.

An important system error was detected during the pilot study, this error was later reported during the interviews to the physiotherapists presented in Chapter 6. The error consisted of the robot being able to talk but not to move, and affected the beginning of most of the sessions. The integration of the tablet interface into the robotic system, and the lack of testing caused this error in the prototype version V1.0.0. The issue was fixed in the next version (V1.0.1) before the case studies commenced. See Table 4.1 for the different versions of the prototype.

Summary of the Pilot Study

Overall, both parents were able to use the robot independently in all the rehabilitation sessions carried out in the pilot study. Parents showed competence to operate the robot and only required assistance to move the robot due to parent anxiety around breaking the robot. Due to a software issue, the system prototype malfunctioned during the set-up in most of the sessions, requiring a quick intervention from the researcher engineer to restore the normal behaviour of the robot. This issue was identified and fixed after the pilot study.

Parents showed enthusiasm for doing rehabilitation sessions with the robot, and the patient exhibited a willingness to interact with the robot via head taps. The mother mentioned that the robot is a good activity to do on the ward in order to fill the patient's schedule. She reported that the patient enjoyed and responded really well when interacting with the robot in the Toy Relay game, but not much during the demonstration of the exercises or the during the introductory speeches. Exercising sit-to-stands with the robot helped the patient to slow down her pace.

The learnings from this trial study provided guidance to the design of the case studies to be presented next, and to future prototype improvements for the integration of the robot on the ward. Table 7.2 provides an overview of the main learnings discussed in this section, and how they influence on the robot's prototype and the design of the case studies.

Table 7.2: Summary of key learnings of the Pilot Study and how I address them for deployment.

Findings from the Pilot Study	Preparation for SAR integration on the ward
The integration of the tablet interface caused an error during the boot-up of the system	The error affecting V1.0.0 is currently fixed for the case studies in V1.0.1
Changes of location are prone to a lack of equipment during the session	Preferably, case studies will run in the same place during the whole case study
Open spaces can be a source of external distractions	Case studies will run in small quiet spaces, preferably at the patient's room
The presence of researchers might have affected the study.	Participants of the case studies will run at least 2 sessions independently without researchers observing.
Parents might be alternating the care of their child, so the study cannot consider only one parent	This is a real world scenario that we cannot control. We will provide a cheat sheet next to the robot with basic instructions for its operation
Some participants when operating the robot can be nervous or anxious	The debriefing with the parents should further examine this matter

7.2 Case Studies Method

For the formal case studies, three families were recruited to participate in a week long case study. This section reports the procedure of the case studies as derived from the pilot study methodological findings. It outlines similarities and differences on participant's recruitment, trial environment, study procedure, and it also reports on the measures used.

7.2.1 Participant Recruitment

Case studies followed the same inclusion criteria as the pilot study. Three families with a child as an inpatient at the Royal Children's Hospital Melbourne were recruited to participate in the study. The inclusion criteria was the following: inpatients for at least a 1 week stay, having a consistent rehabilitation programme with the exercises of the robot, and physiotherapists' clinical judgement.

Table 7.3 provides an overview of all the participants in the case studies. All patients were diagnosed with cerebral palsy, patients included two twin 5 year old males, a 6 year old male, and a 5 year old female patient.

Table 7.3: Case study participants. Patients diagnosed with Cerebral Palsy (CP) with Gross Motor Function Classification System (GMFCS) III or IV.

No	Gender	Age	Diagnosis	Rehab Reason	Session	Place	Parent
F-2	Male and Male	5	CP GMFCS III and CP GMFCS VI	Functional rehab (intensive therapy)	1	Gym	Mother
					2	Patients' room	Mother
					3	Patients' room	Mother
					4	Patients' room	Mother
					5	Patients' room	Mother
F-3	Male	6	CP GMFCS III	Post selective dorsal rhizotomy surgery	1	Patient's room	Mother
					2	Patient's room	Mother
					3	Patient's room	Mother
					4	Patient's room	Mother
					5	Patient's room	Mother
					6	Patient's room	Mother
F-4	Female	5	CP GMFCS III	Functional rehab (intensive therapy)	1	Patient's room	Father
					2	Patient's room	Mother
					3	Patient's room	Father
					4	Patient's room	Father
					5	Patient's room	Mother
					6	Patient's room	Father

7.2.2 Trial Environment

The pilot study elucidated that rehabilitation sessions should run in quiet places, away from external distractions. The patient's room was identified as the preferable option for being the most realistic scenario for a parent delivering rehabilitation on the ward. Thus, almost all the sessions were delivered in the patient's room. Only one session took place in the gym due to the large number of people involved in the session (patients, parents, staff, and researchers).

The robot, the server (laptop), a cheat-sheet with basic instructions, and the tablet interface to initiate the SAR rehabilitation programme were placed in a trolley for easy transport within the hospital as shown in Figure 7.3. Patients did the rehabilitation exercises on their bed with the robot placed on the bed tray table. The bed tray table was just big enough for the robot to do the exercises, however, it was limited for all the posture transitions. Thus, parents were asked to watch posture changes closely. Only the twin patients did the session on two fitness mats on the floor with the robot in the middle. Figure 7.4 shows the hospital setting used in the case studies.

7.2.3 Study Procedure

As in the pilot study, case studies were intended to last 1 week, with participants running at least five daily rehabilitation sessions each weekday. Participants were given an extra day if the weekend was in the middle of the study, to provide them an extra chance to go over the operation of the robot on the Monday after the weekend. Sessions for the case studies proceeded as follows:

Session 1: the treating physiotherapist of the child delivers therapy using the robot as done in Phase 2 study. The parent in charge attends and observes the session, and the research engineer attends to assist with the robotic system if required.

Session 2: the research engineer (author of this thesis) reminds the parent the basic steps to set-up the system. The parent in charge delivers the rehabilitation session as done in Phase 2 study, however, the research engineer observes the session and is available to help if required.

Sessions 3 and 4: the parent delivers therapy with the robot on their own without any assistance from researchers or staff members. No observation data is collected.

Session 5 (optional) session: If the study cannot run from Monday to Friday, parents have an extra day to operate the robot due to the weekend.

Figure 7.3: Trolley used for the case studies to transport the NAO robot and its basic components.

Last session: the parent in charge sets up the robot and delivers therapy with the robot by their own. The research engineer and a physiotherapist attend to observe the parent delivering the session with the SAR.

Parents had the trolley delivered by an Allied Health assistant or a physiotherapist in those sessions where they operated the robot without supervision. Staff members were asked to leave the robot in the patient's room for at least a couple of hours and collect it afterwards. As in the pilot study, the rehabilitation programme was already configured into the system via the tablet interface, and the parent in charge was required to boot-up the system and execute the corresponding session. Parents were also provided with the list of exercises to be done in the session; a cheat sheet of basic instructions for the operation of the robot; and small surveys to self-report their accomplishment after each session (explained in the next subsection).

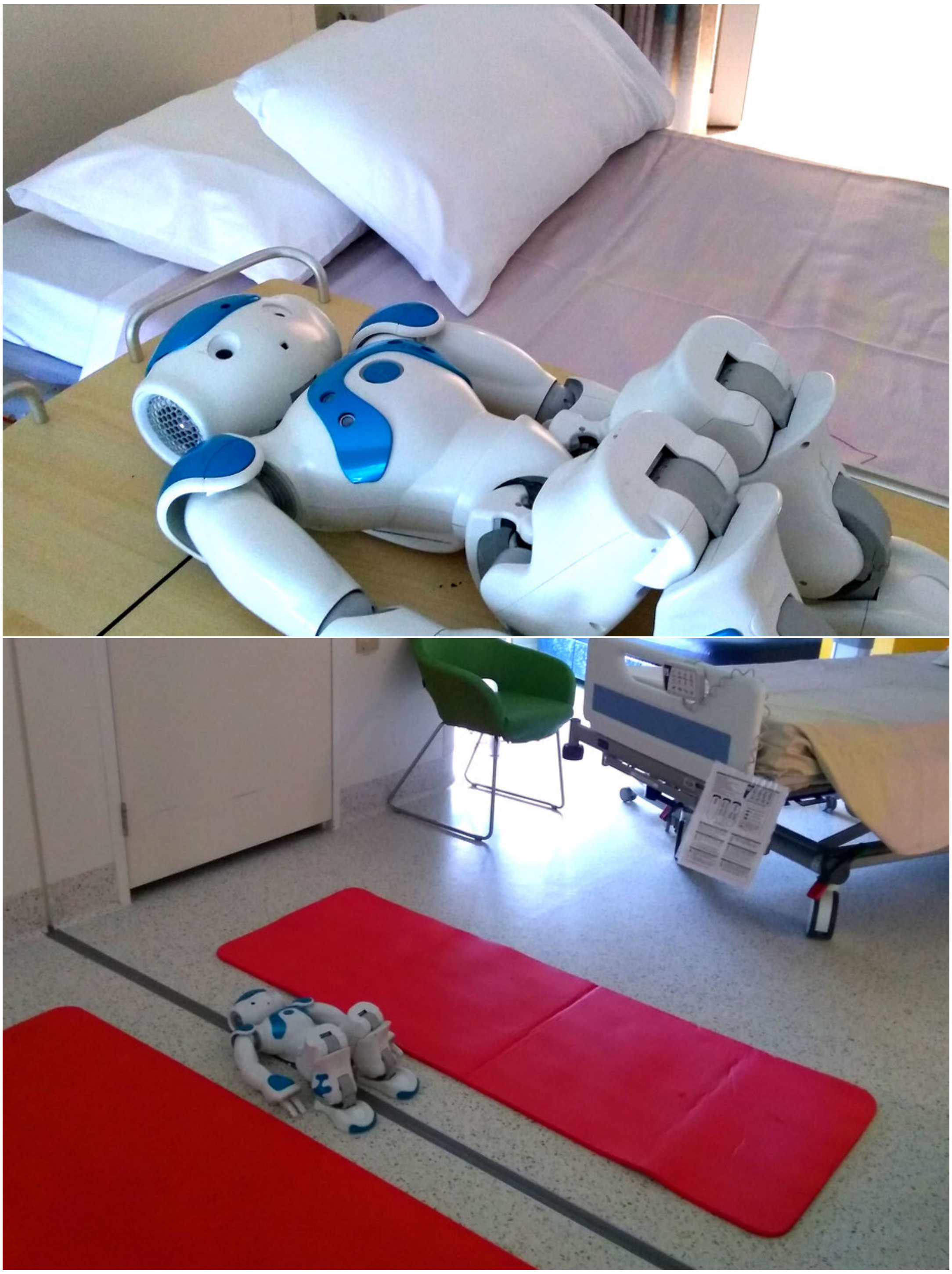


Figure 7.4: Case studies setting. Upper image: the NAO robot on the food tray, next to the patient exercises on the bed. Lower image: the NAO robot on the floor of the room, set up used for the twin patients.

7.2.4 Measures

This study aims to evaluate the integration of the robot on the ward after daily operation and use. More specifically, the patient's mood and compliance over a week period of using the robot, the usability of the system without any assistance, anxiety levels of participants who operated the robot, and the general handling of the session to evaluate the success of the SAR delivering rehabilitation with the assistance of a parent.

As reported previously in the literature (Section 2.3.3), there is a trade-off between participants' privacy when performing studies in private environments such as homes (or in our case in hospital rooms) and collecting enough data for a study. I aimed to run case studies without the presence of researchers, thus in this study I faced the challenge of how to gather data without missing relevant information, or sacrificing the authenticity of the integration study.

Appendix C includes the two forms used to collect data in this study, described bellow.

The Objective Structured Assessment form derived from the physiotherapist's interviews in Chapter 6 was used to evaluate via observations the quality of care delivered using the SAR under the guidance of a parent (Appendix C.5).

The self-report survey was completed by parents after each session of the case studies to gather data from all sessions. This survey aimed to capture the mood of the patient during the rehabilitation session (as reported by the patient and the parent), any technical difficulties during the session, the completion of the exercises by the patient, reasons for not completing the exercises, and an open ended section to provide any other feedback for the researchers. Emojis (small images that can represent different emotions) were also included in the self report in order to prompt and assist patients in expressing different possible emotions. The items in this survey were also derived from the post-Phase 2 interviews. The survey can be found in Appendix C.6.

The self-log of the robot, which captures internal information of the system and the interactions via touch sensors (Section 4.1.7), was also collected for each of the sessions.

A short debrief with the parent took place during the booting up the system in the last session of the case study, and at the end of the session. The aim of the short debrief was to seek information about the following:

- Operation of the robot over the week.
- Any complications when handling the robot and the child without assistance.
- Usefulness of the robot compared with a paper-based list of exercises.
- Any anxiety or discomfort experienced when operating the robot.

7.3 Case Study 1

Participants for the first case study were two twin brothers with cerebral palsy, but with two different levels of the Gross Motor Function Classification System (GMFCS): III and IV (GMFCS described in Section 2.1.1). Staff members reported that the patients had already interacted with the robot in the hospital some months before, during post-Phase 2 use of the robot by therapists. This, however, was not considered an issue with respect to the aims of Phase 3. In addition, while the system was not designed to deliver rehabilitation to multiple patients at the same time, this was considered a valuable and unique opportunity to trial this scenario. For these reasons, the two patients were included in the study.

Different challenges were presented from the beginning of the study, for example: the personalisation of the system for two patients; the number of surveys to collect after each session; and the fact that one single parent had to handle the robot and two children in a rehabilitation session. The system was personalised by alternating the patient's name every other session, however, patients did complain about the robot not referring to them as well as their sibling. An Allied Health assistant, without previous experience with the current system, was available to help in the second and the fourth sessions due to the challenge of delivering rehabilitation to two patients at the same time. The sit-to-stand exercise was removed on the third and fifth sessions due to the unavailability of the Allied Health assistant.

The first rehabilitation session started on Monday and the last one finished on Friday, the mother of the children attended all the sessions and operated the robot according to the study procedure. Even though I aimed to have all the rehabilitation sessions in the patient's room, the first rehabilitation session of this case study took place at the gym due to the large number of attendees: two patients, one parent, two physiotherapists, and two researchers.

For subsequent session, the patients' rooms were merged together into a large single room with enough space suitable to run the rehabilitation sessions. Patients did the rehabilitation with two fitness mats on the floor and the robot in the middle.

7.3.1 Results

The parent was offered the opportunity to fill in two different self-report surveys after each session, one for each patient. However, the parent mentioned that it would be the same for both patients, and so any differences between patients was to be noted. No differences were reported in the self-report survey, thus the self-report results described in this section correspond to both patients.

Table 7.4 provides a summary of the exercises programmed for each session. The results of the self-report survey, and the duration of the session as reported by the logfiles. The assessment of exercises completed was based on the following scale:

1. The patient refuses to do or try to do the exercise.
2. The patient refuses to finish the exercise (e.g. A whole set).
3. The patient does the exercise partly or with lack of interest.
4. The patient easily gets distracted and/or misses some repetitions.
5. The patient does all the sets of exercises.

The completion of the exercises varied among sessions. The main cause reported for not completing all the exercises was patients diverting their attention from the exercises. Other reasons provided were the patients' behaviour or disengagement in the rehabilitation session. Notably, patients completed more exercises when researchers or the Allied Health assistant were present. However, patients were notably less compliant when only the parent was delivering the session with the SAR.

Robot logfiles indicated that parents were able to start the system, and to execute the programmed rehabilitation session for the corresponding day. The duration of the first session was considerably longer due to the robot falling during the sit-to-stand exercise. The robot was placed on a fitness mat which is a less ideal surface. Another technical issue was reported after the fourth session. The robot was not able to stand up. Parent's explanations indicated that a leg of the robot went "out of control". However, the parent successfully restarted the robot and started the session from the required exercise without any assistance. It was observed in the last session that the parent started the robot in upgrade mode, used to upgrade the NAO robot from a USB flash drive. This is done by pressing the chest button of the robot for about 5 seconds. In this mode the robot takes more than 5 minutes to boot up, so the parent successfully restarted the system again.

Both patients, in general, exhibited a positive attitude towards the robot, being happy in all sessions. However, patients also showed signs of becoming frustrated and angry towards the end of the week due to the robot being personalised for the other sibling.

Researcher Observations

Observations were taken on the second and on the last session using the Objective Structured Assessment form (Appendix C.5). The second session (Tuesday) was done with the help of an Allied Health assistance. The last session (Friday) the parent (mother) delivered the session by herself.

Table 7.4: Case Study 1 summary of the results. Case study session number. Exercises programmed by the physiotherapist for the session. Completion of the exercises based on the scale presented above. Reasons for not completing the exercises (if required). Duration of the rehabilitation session from the introductory speech to the farewell dance routine (mm:ss format). Mood of the patient during the session as reported by the parent. Additional comments for the session.

No	Ex. Programmed	Compl.	Reasons	Duration	Mood	Comments
S1	Bridges Hip Abd. Laying Hip Knee Flex. S. Sit-to-Stands	4 4 4 4	Distractions Behaviour Disengagement	30:57	Very Happy Happy Neutral	The robot fell during sit-to-stand exercise because it was on a fitness mat.
S2	Bridges Hip Abd. Laying Hip Knee Flex. S. Sit-to-Stands	4 4 4 4	Distractions Behaviour	18:38	Very Happy Happy Neutral	Allied Health assistant helped
S3	Bridges Hip Abd. Laying Hip Knee Flex. S.	2 3 3	Distractions Disengagement Behaviour	16:54	Happy Neutral Bored	
S4	Bridges Hip Abd. Laying Hip Knee Flex. S. Sit-to-Stands	2 3 4 4	Distractions Behaviour Disengagement	23:22	Happy Neutral Frustrated	Allied Health assistant helped. The robot had to be restarted due to motors overheating
S5	Bridges Hip Abd. Laying Hip Knee Flex. S.	4 3 4	Behaviour Distractions	12:59	Happy Angry Frustrated	Robot started in upgrade mode. Parent decided to restart it.

Observations from the Objective Structured Assessment form indicated that rehabilitation sessions with the SAR were framed like a stimulating activity to do on the ward, where patients showed enthusiasm to do the exercises and having “Rosie” in their room.

During the demonstration of the exercises in the second session, the parent paid attention to the robot while helping their child to get ready for the exercise. Patients also paid attention while getting ready for the exercise. In contrast, during the last session patients were observed to be generally ignoring the demonstrations of the robot while discussing who will tap the robot’s head next. The parent was observed trying to moderate the discussion. Even though participants missed the demonstration of the exercise, they were familiar with the exercises and already knew how to continue with the session.

In both sessions, the parent was observed assisting both children and the robot. The parent was providing prompts, correcting a child’s technique, and redirecting the session when either or both patients lost focus. During the last session the parent alternated between the 2 patients to help with the exercises. As a result, both patients completed less exercises than in sessions with the Allied Health assistant in attendance.

Patient interactions with the SAR, and general behaviour was observed to be variable between sessions. For example, in Session 2, patients interacted with the robot via head taps, were curious about unknown words pronounced by the robot such as *"Superb!"*, and followed the instructions of the parent and the robot. However, in Session 5, patients argued more with the parent and got upset, especially the patient whose name was not being said by the robot. The patient complained and shouted to the robot his name. For example: *"Why did she [the robot] say [brother's name]? I want her to say [his name]!"*. Patients were also willing to interact with the robot via head taps on Friday's session, however, discussions about who will tap the robot's head escalated. Both brothers were observed tapping repeatedly at the same time the robot's head, and sometimes showed anger yelling: *"YOU DO NEXT!!"*.

Rehabilitation sessions on the ward had no major distractions. The two observed sessions had two short interruptions by staff members. Interruptions occurred to schedule other activities for the patients, and for afternoon tea.

Overall the parent showed competence and confidence when operating the robot in the last session. By her own initiative, the parent decided to reboot the system when an error happened, or when it took too long to boot up the system. Patients expressed concerns when the robot took longer time to boot up than the previous sessions. The parent also did not show any kind of concern or discomfort when dealing with the robot.

During the debriefing with the parent after the last session, the parent commented that using the robot in rehabilitation is more useful than using the list of exercises. The robot is more interactive and talks to them, however, it is too difficult to do exercises with both children at once alone. Patients get easily distracted and become upset, thus she commented that the robot with one child will work much better.

7.3.2 Case Study 1 Findings

Here I outline the main findings from Case Study 1 which are categorised as follows:

- Rehabilitation for Multiple Users.
- Learnings for Integration and Evaluation in Hospital Settings.
- Use of the Robot by Non-Technical Users.

Rehabilitation for Multiple Users

The parent reported that delivering rehabilitation for two patients alone was too complicated, it is better to do one patient at a time. It was observed in the pilot study that delivering certain rehabilitation exercises with the SAR can be challenging if the child requires significant attention. For example, when doing the sit-to-stand exercise. In this case study, the sit-to-stand exercise had to be removed from the programme when the Allied Health assistant was not available to assist with one of the twin brothers. Helping one child with the exercises, giving verbal instructions to correct the technique of the other child, while moderating discussions between brothers about who interacts with the robot was observed to be very challenging for a single adult operator. Patients were also observed being more focused when they had someone dedicated to them helping with the exercises.

Another issue noted about our SAR prototype with multiple patients is that the system is not prepared to be personalised for all the users. The strategy of alternating the names of the patients seemed to work at the beginning of the session when one patient said: *"The robot knows our names!"*, however, by the end of the session the same patient complained because the robot was only saying his brother's name. These reactions indicate that patients highly value the personalisation of the robot. If intending to do rehabilitation sessions with multiple patients at once, appropriate design decisions are needed to ensure personalisation of multiple users, and coordination of the different patients and robot interaction.

Learnings for Integration and Evaluation in Hospital Settings

Different locations were explored during the pilot study to run the rehabilitation sessions. The patient's room was considered one of the best options due to its availability and reduced distractions. However, external interruptions also occurred on the ward by staff members as observed on the second and fifth sessions. The parent also reported that they had to close the door of the room because someone complained about the volume of the robot, most likely the parent of another patient. It is important to allow users to adjust the loudness of new technology for the successful integration on the ward. Further development of the prototype should include a volume control from the tablet interface.

Running experiments in hospital settings during a week can be challenging to schedule and perform. Particularly in this case study, we had to manage the schedule of two patients with only one parent available, as well as a shortage of available staff to assist. Even though patients had similar schedules, it was not easy to find a gap that could fit both patients, the parent, and an allied health assistance or a nurse. When trying to reschedule other participant's appointments within the hospital (such as occupational therapists, or orthopaedics), it would have affected other staff members and it would have escalated to other patients. Thus, the most viable solution after comparing different calendars and trying to reschedule appointments, was the parent alone delivering rehabilitation to both children at once. Such in situ evaluation methodologies must therefore be designed to be tolerant to, and compliant with other staff members and patient priorities.

Use of the Robot by Non-Technical Users

The parent observed a physiotherapist operating the robot in the first session, operated the robot in the second with the support of the research engineer, and then operated the robot independently in three sessions on the ward. The parent was able to overcome the issues that occurred in Sessions 4 and 5 independently, restarting the system if required. However, during the time taken from the robot to be restarted, children were prone to distraction, and sometimes worried about the robot, asking repeatedly: *"What is wrong with Rosie?"*.

The use of a general-purpose robot not specifically designed to deliver rehabilitation exercises is prone to technical issues such as motors overheating. Independently of the training provided to the operator of the robot, system disruptions can always occur and disrupt the session distracting patients. Thus, backup plans are important strategies to implement. Furthermore, robots designed for physical demonstration in rehabilitation scenarios should consider appropriately robust joins and motors to handle the wear and tear of daily use, and faster reboot times.

7.4 Case Study 2

The patient for the second case study was a 6 year old male with cerebral palsy (Gross Motor Function Classification System III). Staff members commented that the patient had interacted previously with the robot, most likely during post-Phase 2 use of the robot by staff.

Sessions started on a Wednesday, and so accordingly to our study protocol, six rehabilitation sessions were scheduled due to the weekend break. All the rehabilitation sessions were carried out in the patient's room. The mother of the child operated the robot in all the sessions.

7.4.1 Results

Table 7.5 provides a summary of the exercises programmed for each session, the results of the self-report survey, and duration of the session as reported by the logfiles. The self-report survey for the fourth session was missing, and so could not be used for data collection.

Table 7.5: Case Study 2 summary of the results. Case study session number. Exercises programmed by the physiotherapist for the session. Completion of the exercises based on the scale presented above. Reasons for not completing the exercises (if required). Duration of the rehabilitation session from the introductory speech to the farewell dance routine (mm:ss format). Mood of the patient during the session as reported by the parent. Additional comments for the session.

No	Ex. Programmed	Compl.	Reasons	Duration	Mood	Comments
S1	Quads over Roll Hip Abd. Laying Hip Knee Flex. S.	4 4 4	Distractions Too excited	12:34	Happy	Quads over Roll not executed because the exercise speed was not selected
S2	Quads over Roll Hip Abd. Laying Hip Knee Flex. S.	4 4 4	Distractions	13:25	Happy Very Happy Neutral	
S3	Quads over Roll Hip Abd. Laying Hip Knee Flex. S.	4 4 4	Distractions	10:45	Happy	
S4	Quads over Roll Hip Abd. Laying Hip Knee Flex. S.			11:16		Self-report lost. Robot started in upgrade mode. Parent decided to restart it.
S5	Quads over Roll Hip Abd. Laying Hip Knee Flex. S.	4 4 4	Distractions	14:35	Very Happy Happy	Robot started in upgrade mode. Parent decided to restart it.
S6	Quads over Roll Hip Abd. Laying Hip Knee Flex. S.	 4 4	Distractions	07:19	Very Happy Happy	Parent started the session from Hip Abd. Laying. Robot started in upgrade mode.

The level of exercise completion was very similar in all the rehabilitation sessions. The patient was mostly doing the exercises but observed to be also prone to distraction. The main reason reported was distractions due to the patient being too excited by the robot. This is also reflected in the mood of the patient as reported by the parent, which was between very happy and happy in most of the sessions. The good mood of the patient was maintained until the end of the study. The parent noted that the patient was very excited because of the robot.

Inspection of the robot logfiles confirmed that the system was correctly started in all the sessions, and all the exercises were executed. All the sessions except for the last one had similar length of time. This is because the parent, by her own initiative, decided to start the rehabilitation from the Hip Abductions exercise instead of starting from the introductory speech. This option is available in case the robot malfunctions, so the system can be restarted and resume operation from the last exercise completed. The parent wanted to alter the order of the session because the patient had knee extension splints attached which had to be removed for the Quads over Roll exercise, but they were necessary for the Hip Abductions exercise.

Researcher Observations

Observations were taken using the Objective Structured Assessment form (Appendix C.5) in the second session on Thursday and in the last session on Wednesday of the following week.

The patient was very excited to do exercises with the robot in all the sessions, so the parent did not have to make any specific effort to initiate or frame the session as a fun activity. The robot's presence appeared to achieve this.

While the robot was demonstrating the exercises, the parent pointed out key aspects of the exercise to keep the patient focused and comprehend the exercise. However, the patient seemed to be too absorbed by the robot, staring at it, and not paying much attention to the parent. The patient was also observed in early sessions to be tapping the robot's head continuously during the demonstrations, but in the last session the patient asked for permission from the parent to tap the robot's head.

The parent engaged in the observed sessions, assisting the child and the robot during the exercises. She provided encouraging statements, including verbal and visual prompts to the patient. In the last session, the parent also used prompts from the robot to correct the child's technique. The parent also was observed bringing the robot closer to the child for better interaction.

On the other hand, the patient was doing the exercises while watching at the robot. They were willing to interact with it via head taps. The patient seemed, at times, too focused on the robot and not enough on the rehabilitation exercises, however, he followed the instructions and prompts provided by the parent during the exercises. The patient showed enthusiasm for the final dance routine of the robot.

Sessions observed in this case study ran without any apparent external distractions, even though other family members were present in the room. Overall, the parent showed competence starting the system and operating the robot, exhibiting confidence and comfort with the robot. Notably, the parent also took advantage of the cheat-sheet provided to start the robot and execute the session.

During the last session debriefing, the parent explained that she restarted the system in the fourth and fifth sessions (Monday and Tuesday) because the robot was taking too long to boot up. Last session observations indicated that the parent started the robot in system upgrade mode, as was also observed in Case Study 1, which takes more than 5 minutes to boot up. Normally the NAO robot only requires a single press on the chest button to boot up. If held for 5 seconds or more the robot boots up in upgrade mode.

When asked if they had any concerns or feelings of anxiety when using the robot by themselves, the parent reported that she "felt fine", and just followed the instructions given to her:

> *I just get closer to [the robot] and help, keep an eye to prevent [the robot] falls. (Parent of Case Study 2)*

The parent also mentioned that handling the robot was not difficult. She followed the cheat-sheet provided and figured out how to make it work. The only concern the parent expressed was when the robot took too long to boot up.

The parent commented that doing exercises with the robot is better than doing exercises with a printed handout, but doing the exercises with the physiotherapists was still preferred.

7.4.2 Case Study 2 Findings

Key findings from this case study can be categorised as:

- Parent Independently Using of the Robot.
- Execution Order of the Exercises.
- Learnings for On-Ward Integration and Evaluation.

Parent Independently using the Robot

After the second session, the parent asked for a person of reference to ask for help if required. Due to the goal of the study not providing technical assistance, the parent was instead referred to the cheat-sheet and invited to note in the self-report survey any issues that arose in the session.

The system performed reliably and without any technical failures. The only issue reported was the long time required by the robot to boot up, similarly to last session of the first case study. A short single press is required to start the NAO robot, but a long press is required to shut it down. This caused confusion among participants, who mistakenly started the robot in upgrade mode in later sessions by long pressing the robot's power button. This boot up option of the NAO robot takes more than 5 minutes, and cannot be changed. Thus, future studies that intend non-technical users to operate a robot or new technology, especially in busy contexts such as hospitals, should remind and emphasise to users any key details of the correct setting up process. Alternatively, clear annotations in a cheat-sheet next to the robot can help participants to prevent such incidents. While in this case study the long waiting period did not affect negatively the mood of the patient, patients from previous studies got distracted or upset for long waiting periods. The parent decision to restart the robot could have increased the total waiting time to start the system.

Another confusion observed with the chest button of the NAO robot was when it was pressed once while the robot was already on. The robot reports technical information such as its IP address among other technical details. Non-technical users do not understand what the robot is trying to say, and sometimes do not know how to proceed. This is another feature of the robot that cannot be altered which can reduce the usability of the robot. These embedded features of the NAO robot, while useful for researchers or technology developers, can impact negatively non-technical users' trust and confidence when operating or interacting with SARs. Ideally, robots to be used in the wild, by the intended final users, should incorporate mechanisms to easily cancel those features which are not required for the final application.

Execution Order of the Exercises

To be able to alter the order of the exercises has been previously reported as something desirable. Notably, this was also noted by physiotherapists during the Phase 2 study (e.g., Section 3.3.3). However, in order to reduce the wear-and-tear of robot when transitioning from standing to lay down and vice versa, the order of the exercises was decided to remain fixed, primarily due to limitations of the tablet interface for session configuration.

In this case study it was observed a very clear example why the parent of the session should be able to alter, with certain limitations, the order of the exercises. The patient had initially attached the knee extension splints, and those were required for the second exercise (Hip abductions) but they had to be removed for the first exercise (Quads over roll).

Ideally the order of the exercises should be exchangeable in certain blocks. For instance, the robot can have 4 blocks: introductory speech, exercises from a laying down position, exercises from a standing position, and the farewell dance. Exercises within those blocks should be completely exchangeable as desired by the facilitator of the session. Also the entire block of exercises from a laying down position should be able to be swapped with the entire block of exercises from a standing position.

In order to integrate the robot for the needs of the clinical ward, future improvements of the system prototype should allow the re-ordering of the exercises as desired by the facilitator of the session.

On-Ward Integration and Evaluation

The challenges of running studies in private environments and collecting data were previously reported. Self-report measures were the most suitable way to obtain data while preserving participants privacy in our study. Even though the survey of the fourth session was not recovered, I believe that the lost of data did not affect significantly the results of this case study. Other daily surveys, robot logs, and the debrief at the end of the last session complemented the results for the missing data. Such issues emphasise the importance of collecting and combining different modalities of data, particularly for uncontrolled in situ studies such as this. Surveys in this study were provided on paper, which increased the chances of missing them. An alternative could have been to provide electronic surveys from the tablet interface that controls the robot at the end of the sessions.

Collecting data via observations in the patient's room can also be challenging. While the study procedure indicates the therapist and the researcher just observe, the presence of the therapists was misunderstood by the parent who expected the therapists to take part in the session. To prevent such situations, participants should be reminded about the roles of the attendees before running the sessions.

Unlike the previous case study, I did not observe interruptions during the rehabilitation session. However, lunch was being delivered on the ward when starting the system for the last session. Studies on the ward should also consider those regular scheduled events to minimise disruptions.

7.5 Case Study 3

The patient of the last case study was a 5 year old female with cerebral palsy (Gross Motor Function Classification System III). Six daily rehabilitation sessions were scheduled starting on Thursday, and finishing on Thursday of the following week. No rehabilitation sessions were scheduled during the weekend as per the study protocol. Both parents alternated the care of their child depending on the time of the day, and their last minute commitments. The father of the patient operated the robot in the first, third, forth, and sixth sessions; and the mother in the second and fifth sessions. This affected the planned training for the caregivers from 2 sessions to only one for each parent. All the rehabilitation sessions were done in the patient's room.

7.5.1 Results

All the sessions were programmed with the same set of rehabilitation exercises. Table 7.6 provides a summary of the exercises programmed for each session, the results of the self-report survey, and duration of the session as reported by the logfiles.

Table 7.6: Case Study 3 summary of the results. Case study session number. Exercises programmed by the physiotherapist for the session. Completion of the exercises based on the scale presented above. Reasons for not completing the exercises (if required). Duration of the rehabilitation session from the introductory speech to the farewell dance routine (mm:ss format). Mood of the patient during the session as reported by the parent. Additional comments for the session.

No	Ex. Programmed	Compl.	Reasons	Duration	Mood	Comments
S1	Quads over Roll Bridges Hip Abd. Laying Hip Knee Flex. S.	5 5 5 5		22:29	Very Happy Excited	
S2	Quads over Roll Bridges Hip Abd. Laying Hip Knee Flex. S.	5 5 5 5		20:10	Happy	The robot fell at the end
S3	Quads over Roll Bridges Hip Abd. Laying Hip Knee Flex. S.	3 3 3 3	Exhaustion Distractions Disengagement	19:13	Disengaged Very Happy	Busy day for the patient, no time to rest. The robot fell at the end.
S4	Quads over Roll Bridges Hip Abd. Laying Hip Knee Flex. S.	3 3 3 3	No reasons provided	19:59	Happy Bored Disengaged	Bridges too fast, parent could not change pace. The robot fell at the end.
S5	Quads over Roll Bridges Hip Abd. Laying Hip Knee Flex. S.	5 5 5 5		19:39	Happy Afraid Very Sad	Afraid when the robot “went crazy” at the end and could not get up. Sad it did not dance.
S6	Quads over Roll Bridges Hip Abd. Laying Hip Knee Flex. S.	5 4 4 4	Disengagement Distractions	21:06	Happy Bored	

The completion of the exercises varied depending on the day. In the first, second, and fifth sessions, the patient was reported doing all the exercises. In the third session parents reported the patient had a busy day in the hospital, so exhaustion was the main reason for doing the exercises partially. No reasons were provided in the fourth session for completing the exercises partially, however, a note was made that the parent tried to alter the speed of the exercises because it was too fast. In the last session the patient missed a few repetitions due to disengagement and distractions.

The robot logfiles indicate that the SAR was successfully started in all the sessions. All the programmed exercises were executed, and all the sessions had a very similar duration in time. Parents reported that the robot fell at the end of the second, third, and fourth sessions. In the fifith session, the robot lost stability when standing up, so it could not perform the final farewell routine. This was also reflected in the reported mood of the patient, which was noted as afraid when the robot could not stand up, and very sad because the robot did not dance. Apart from that, parents reported the patient's mood as very happy or happy in all the sessions, but in later session the patient started being disengaged or bored.

Researcher Observations

The Objective Structured Assessment form (Appendix C.5) was used as a guide to collect observational data of the first, second, and last rehabilitation session. The second rehabilitation session was operated by the mother, and the last one by the father. This observational data is reported below.

Sessions were framed as an interesting activity on the ward. The patient was curious about the robot, and showed enthusiasm to do rehabilitation.

During the demonstration of the exercises parents, and the patient, paid attention to the robot demonstration. Parents used it to indicate or to remind themselves of key aspects of the exercise to the patient. In the last session, it was observed that the patient already recognised an exercise by the name, and indicated to the parent that they did not need help with that exercise.

During the execution of the exercises, parents were assisting their child when required and operating the robot. Parents were correcting the patient's technique when required, providing verbal prompts, and encouraging statements. The father was also observed using prompts and encouraging statements from the robot, whereas the mother expressed satisfaction when tasks were completed.

The patient showed a willingness to interact with the robot via head taps. She was doing the exercises, following the instructions of the robot and her parents, while commenting on certain aspects of the exercises such as which parts of the exercises were hard or easy. In the last session, the patient was observed to be worried about the robot falling when standing up.

Two external interruptions occurred on the last session. The first one happened when booting up the system and the second interruption during the exercises. A healthcare team doing a consultation round on the ward was prevented from entering by the physiotherapist researcher.

Overall, both parents showed competence operating the robot, and facilitating the rehabilitation session. However, parent feedback indicated that the robot lost stability in most of the rehabilitation sessions at the final farewell routine.

The debrief after the last session was done only with the father, and was shorter than planned due to the participants' other commitments in the hospital. The parent commented that the system was easy enough to set up and operate. He made use of the cheat-sheet and was able to "make it work". No concerns or anxieties were reported by the father when asked. The parent also mentioned that the robot was useful at the beginning, but he perceived that the novelty wore off quickly for the patient, so she started getting distracted. He also suggested that the time of the day affects how the patient performs the exercises. This particular patient was more active and focussed during morning sessions according to the father.

7.5.2 Case Study 3 Findings

The last case study of this chapter brought new learnings for SAR integration on-ward in daily use. I report new insights and also complement previous findings from the previous case studies. The findings are grouped as follows:

- On-Ward Integration and Evaluation.
- Importance of Training and Resources to Caregivers.
- Use of Technology by Participants.
- Novelty Effect of the SAR.

On-Ward Integration and Evaluation

I have already reported in the previous case studies the challenges when scheduling rehabilitation sessions for this study. In this case study, the patient's exhaustion affected her completion of the exercises in the fourth session due to her busy day in the hospital. Physiotherapists already indicated during the interviews in Chapter 6 that the other activities happening on the ward can be barriers for the patients' completion of the exercises. The forth session was programmed to be done by the mother, however, the father operated the robot due to last minute arrangements. The system is not prepared to allow parents to alter the name of the facilitator of the session. Thus, parents reported that the patient got distracted when the robot was referring to her father as a ‘mum’. This indicates correct customisation is crucial to the robot’s authenticity, thus, SARs in such contexts should offer certain flexibility to adapt to the parents needs. Previously, I have suggested how the facilitator of the session should be allowed to alter the execution order of the exercises. In addition to that, the name of the facilitator of the session should be easy to modify.

All the case studies have reported some sort of external interruptions causing distractions to the participants when running rehabilitation sessions, however, most of the distractions reported came from staff members during regular working hours. Even though the robot can be paused during the session when an interruption occurs (Section 3.3.7), physiotherapists reported that patients should be focused during their exercises, and distractions should be minimal. The final intended use of the robot is on the ward after hours, thus, interruptions on the ward might be reduced due to less personnel working during evenings and weekends.

Importance of Training and Resources to Caregivers

Parents alternated the care of their child depending on the time of the day, and their other commitments outside the hospital. This challenged the intended training described in the study protocol, which instead of 2 training sessions parents had 1 each. To prevent long waiting periods when booting up the system, in this case study I put more emphasis on the steps to start the robot (short chest press). Parents were able to successfully start, operate the robot, and deliver rehabilitation, however, they reported that the robot lost stability at the end of most of the sessions, during the dance routine. This is normally prevented by the facilitator of the session keeping a close eye on the robot, and holding it if required. The reduced training in this case study, due to parents alternating their sessions, might have influenced in how parents dealt with the robot losing stability. Robot falls effected patient’s emotions when the robot transitioned to a standing or a laying down position. The patient expressed her worries by avoiding watching between such transitions. This indicates that there is an emotional connection between the child and the robot. Studies in those contexts, especially when training is limited, should provide clear instructions to participants. For instance, the robot could remind the parent to get closer, and prevent the robot fall.

Use of the Technology by Participants

Changing the speed of the exercise in execution was something requested by therapists at early stages of the project. The tactile interface (Section 3.3.7) was implemented in order to allow the operator of the robot to alter the speed of an exercise if required. However, observations during the Phase 2 study indicated that physiotherapists became familiar with the speed of the exercises, and they did not require to modify the speed of any exercise. After a few testing attempts with the tactile interface, the decision was made to simplify the interface to make it more usable (Section 4.1.3). This simplification of the tactile interface caused some patients to inadvertently changed the speed of the robot during the demonstration of the exercises due to their craving for tapping the robot's head. Future improvements of the system could remove speed changes from the tactile interface, and include those options in the tablet interface only, or potentially provide a tactile option that is less prone to error, primarily as a backup to the tablet.

Bers et al. [11] in their study with a computational storytelling environment ran sessions on the children's bedside at the Boston's Children's Hospital. The authors reported that leaving the computer in a public space attracted other patients and families who inadvertently altered the system. In this case study I have experienced a very similar scenario with the server that controls the robot. The laptop, which acts as a server for the robotic system, had the same username and password as the tablet interface. No interaction with the server is required apart from turning it on to start the system, and turning it off at the end of the session. However, after collecting the laptop in one of the sessions I observed an unauthorised access into the system. This is not desirable because it can misconfigure the robotic system, and might bring privacy concerns for the future deployment of the robotic platform.

Novelty Effect of the Socially Assistive Robot

Daily use of the robot directly addresses the question of the SAR's novelty effect. In this case study, one of the parents noted that the robot's novelty appeared to diminish over the week, and this impacted the session. This brings an interesting question not addressed so far: over what duration can our prototype SAR sustain positive engagement with a patient, and what factors influence this? I did not formally test patient's compliance with the exercises over time in this study. In fact, to the best of our knowledge no previous work has explored the novelty factor of a SAR delivering paediatric rehabilitation on a daily basis. In general, studies with SARs in paediatric rehabilitation have delivered rehabilitation on a weekly basis [67, 78, 132, 173, 176, 235]. Results in the case studies presented indicate that the impact of novelty is variable, and therefore complex to measure. Previous chapters already indicated that some patients noted the lack of responsiveness of the robot

7.6 Objective Structured Assessment Critique

The Objective Structured Assessment form (Appendix C.5), derived from physiotherapist interviews, was successfully applied across all formal case studies presented in this chapter. Overall, the observable items used to gauge the quality of care delivery using a SAR without physiotherapist supervision was found to provide useful guidance, as well as underlying confidence in the observations being made. I argue that such an approach to assessing SARs in their delivery of care offers benefits for understanding how the robot integrates with care delivery, and the approach outlined in Chapter 6 for deriving the metrics may readily be applied in other application settings. Notably, however, some challenges were experienced in this application, which I outline here.

For instance, one of the themes derived from the interviews, ‘Technique’, requires input from the physiotherapists’ expertise, thus, it cannot be evaluated by researchers without a physiotherapy background. This complicated the design of the case studies, requiring scheduling to ensure a qualified physiotherapists was present. Furthermore, physiotherapists reported that the evaluation of the technique via observation is also sometimes difficult to determine. Physiotherapists might require to manipulate the patients’ body limbs in order to assess the correct technique of the exercises. Notably, these issues are not specific to the SAR’s evaluation, and is indeed inherent issue for the Objective Structured Assessments generally.

Other challenges presented during the case studies was related to the design of the observation form, and its usability when observing sessions. The form is designed to go back and forth though its pages to tick off the different items, repeating the process for each exercise. This caused some observations to be missed, and also assumed reasonable familiarity with the underlying meaning of the observations. While the items listed would likely be sufficient for trained physiotherapists, it was found to be challenging for non-therapist observers such as myself.

In general, these noted challenges may be easily addressed through both experience, and more appropriate tools to support data collection. For example, an appropriately design tablet-based application may be considered to support observation entries, providing easy access item to check off as observed, but also a growing bank of used-added observations that become part of the observation list. If video-based assessment is possible, then clearly issues of missing events would be alleviated, though this may be difficult to implement for privacy reasons. Future work will consider such improvements.

7.7 Limitations

The main limitation of the case studies presented in this chapter is the low number of participants, limiting the generalisations of these findings. However, themes have been identified supported by findings from previous chapters of this thesis, or suggested new design decisions for the daily use of the prototype system.

One of the goals of the case studies was to explore the integration of the SAR on the ward, with the final goal of testing it after hours when physiotherapists are not around. The study was limited in this aspect due to complications with the storage of the robot and unavailability of the personnel to bring it into the patient's room, thus, all the sessions run during working hours on the ward. This increased the number of interruptions and distractions by staff members. However, such interruptions also provided an authentic in situ evaluation settings, providing critical insights into what on-ward integration entails in a busy hospital.

Some data collected included observation notes from researchers present during the rehabilitation sessions. This might have influenced the participants' behaviour compared with non-observed sessions. Furthermore, the results of the study might have been influenced by the subjective observations of the researchers. However, observations were taken following the Objective Structured Assessment form derived from the interviews to physiotherapists reported in Chapter 6.

The robot logfiles report if the robot was started and executed the exercises. However, the logs do not report the patient's completion of the exercises, which are reported subjectively by the facilitator of the session. Even though I introduced emojis to prompt different emotions to patients, most of the patients were not cognitive enough to understand them. Thus, patient's mood has been reported by the parent of the session and not directly by the child.

7.8 Summary

In this chapter I have explored the daily use of the SAR delivering rehabilitation exercises. Four families with an inpatient at the Royal Children Hospital in Melbourne were recruited to participate in 1 pilot study and 3 case studies. Parents operated the robot independently and delivered rehabilitation to their child during a week, without researchers and minimal physiotherapist support.

Families had two training sessions, which consisted of observing a therapist facilitating a session with the robot, and a second session where they operated the robot with the assistance of the researcher engineer if required. Families delivered rehabilitation independently for 3 or 4 days, and the last session was observed by the research team. In general parents showed competence and confidence when operating the robotic system, and most did not express any concerns or anxieties when using it independently. Based on observations using the Objective Structure Assessment form, facilitators have successfully delivered rehabilitation with the help of the robot on the ward.

Patients' completion of the exercises varied depending on the patient, their behaviour, and if they got distracted or disengaged. In general all patients had a positive attitude towards the robot throughout the week, however some observations indicated waning interest in the robot by the last session of one patient.

The daily operation of the SAR by the final users in the intended place of use, has brought new insights not reported previously during the Phase 2 weekly evaluation of the prototype (Chapter 5) or elsewhere in the literature. I argue that this Phase 3 study, in combination with Phase 1 and Phase 2, provides a multi-faceted exploration of SAR design and integration into a hospital setting. I further argue that such an approach is critical to gaining acceptance, and achieving integration of such technologies in clinical settings.

Table 7.7 provides a summary of the challenges and the lessons learned during the case studies in order to successfully integrate the SAR on the clinical ward in daily use by non-technical users. The table groups the related items together which are: lessons learned for studies on the ward, families independently using the system, system improvements to equip families to use the SAR independently, and novelty factor issues.

Table 7.7: Summary of challenges and lessons learned from the case studies system improvements for a successful integration on the ward.

Challenges from Case Studies	Lessons Learned
Location of the rehabilitation	The patient's room has been the most viable place on the ward for parents deliver rehabilitation independently
Sessions on the ward interrupted by staff members	The robot is intended to be used after hours where the number of interruptions should be reduced
Daily sessions have been complex to schedule due to families' commitments, or short staffed therapists.	Studies in such contexts should be able to adapt to the changing needs of the environment. Ideally, a researcher on site with time allocated for the logistics of the study.
Unathorised access into the server	Technologies used in such critical contexts should consider all possible breach of privacy, and protect their systems accordingly.
Survey questionnaire lost	Studies in such contexts should combine different ways of data collection in order to support possible data loss. Integrating surveys with other electronic devices used in the study, such as the tablet interface, should be explored.
Families delivering rehabilitation with the SAR independently	Families with 2 sessions training have successfully been able to deliver rehabilitation independently

Some families reported the robot taking too long to boot up due to confusing switch on/off steps for the NAO robot	Training and the cheat-sheet should remind parents how to switch on/off the robot
Some families reported the robot losing stability	The robot should ask to be watched closely when standing up or laying down
Twin brothers doing rehabilitation	The system should be improved to allow personalisation and co-ordination of multiple patients. If patients are not independent enough, one facilitator per patient is required to assist them.
Sessions on the ward can disrupt other families	The robotic system should allow families to adjust the volume from the tablet interface.
A parent wanted to start the session from a different exercise	The facilitator of the session should be able to alter the order of the exercises within certain blocks
Parents last minute arrangements changed who will deliver the rehabilitation session	Parents should be able to modify the name of the facilitator of the session from the tablet interface
Parents have been unable to change the speed of an exercise, while several patients have done that by mistake.	The tablet interface should allow alterations of the speed of an exercise in execution, the tactile interface should not include this option.
Parent reported that novelty of the robot was not maintained by the end of the week.	This question has still not been properly explored. Studies reviewed in the literature delivered rehabilitation in a weekly basis. Future work should explore the novelty effect of the robot.

These Phase 3 findings can be summarised as:

- The relative importance of some roles, deemed important from Phase 1 and Phase 2, changed when using the robot in daily sessions. In particular, the robot's demonstration of the exercises became a source of distraction for patients already familiar with the exercise, suggesting options to skip this should be incorporated.

- Users who highly value the personalisation of the SAR during the interaction might have negative reactions if the robot does not appropriately refer to them or their carer. Patients were observed to be distracted, less compliant with the exercises, or even expressing anger.

- Long periods of waiting for the robot to boot up was observed to either distract patients, or effect them emotionally such as being worried and asking what is wrong with the robot. This was a new issue in Phase 3 because the robot was always ready at the beginning of Phase 2 studies.

- Expressions of worry by patients when the robot lost stability suggest an emotional connection is being made during the sessions. Such findings confirm a central role of the SAR as a companion, but must also be appropriately designed for to ensure positive emotions and minimal distractions from the exercise programme.
- The cheat-sheet next to the robot was a useful source of reference for the operator of the robot in this Phase 3 study. Technology developers should carefully consider the design of such short reference manuals when intending to introduce SARs in on-ward settings in order to improve the usability of the systems.
- Initial requirements for the design of SARs included a stand-alone robot for rehabilitation. This requirement as been key to the success of Phase 3, where a portable robot not requiring calibration or a dedicated environment has been able to deliver rehabilitation in different locations without technical assistance.
- Configurability of the system has been confirmed as critical, and central to the SAR's successful deployment in Phase 3 evaluations. Through this feature, parents were able to start the SAR with the corresponding session programmed, with sessions adaptable by therapists for each day. Further configurability could easily be included in the tested system, and in general, as many options as possible to adapt sessions to patient needs should be supported in any SAR designed for clinical deployment.
- Interruptions on the ward are unavoidable, thus SARs should be designed with this in mind. Simple examples include providing easy ways to pause the rehabilitation session in execution. Advances in artificial intelligence may also detect such events, and self-pause, or ask for confirmation to continue.

Chapter 8

Discussion, Conclusion and Future Work

Chapters 3 through 7 have presented the key contributions of this thesis, following my three-phase in situ design, development and evaluation methodology. In this final chapter I present an overall discussion of the results presented, and relate these results to the original research questions of this thesis. Through this discussion, I highlight key findings for the design of Socially Assistive Robots (SARs) for ongoing clinical deployment, and broader implications for the design of SARs in health care settings generally. Finally, the chapter provides future research directions for this research.

8.1 Concluding Discussion

This section presents the key learnings and recommendations for the development of SARs for ongoing clinical deployment. Specifically, the section discusses how the initial roles of the robot performed in the different phases of the project. It also discusses and critiques the in situ design process presented in this thesis, and the factors that impacted on the participants' attitudes towards the robot. Finally, this sections outlines lessons learned for the integration of a SAR on the ward.

8.1.1 Roles and Requirements on SAR in Ongoing Clinical Deployment

The roles of the robot derived from the Phase 1 (Demonstrator, Motivator, Companion, and Coach) have been, in general, proven effective in patient sessions, and generally well received by participants. Other SARs in the literature have generally not considered a design methodology to explore specific roles and functionalities to support paediatric rehabilitation [67, 78, 132, 176, 235]. Thus, their systems generally vary from the system presented here, or incorporate only a sub-set of the roles (e.g., demonstrator or motivator alone). The early identification of the roles at the beginning of the project established them as a requirement, thus the roles themselves remained unchanged. However, at different stages of the evaluation it was clear that some roles exhibited more importance than others, and this depended on the context.

For example, the Demonstrator role was perceived by therapists and parents to be most beneficial during Phase 2 weekly testing. However, observations and patient feedback during Phase 3 multi-day case studies indicated demonstrations became tedious and less important due to the patient's growing familiarity with the exercises over the 5 days testing. It is challenging to predict from a weekly exploratory phase, all the future variables and considerations for the system. In general, exploratory studies benefit from the interaction of different users rather than focusing on a single user over multiple uses. Researchers seeking to develop a system for long term use might also consider to incorporate in their exploratory phase studies of multiple interactions with a single participant.

The Motivator role of the robot was also found to provide benefits during the weekly evaluation of the system, however, this phase did not sufficiently explore the impact of reduced novelty over time on the SAR's motivational benefits. While Phase 3 extended the number of sessions per patient with the SAR, it is difficult to make any clear conclusions on reduced novelty factor and its impact on motivation. The literature reports similar studies, however, none of them used the robot in daily basis [132, 177]. Thus, the novelty factor is still an open research question.

Patients, in general, indicated that the final dance routine was their favourite feature of the robot, suggesting entertainment is a key driver of the system's motivational benefits, similarly to Vircikova and Sincak [235]. Ideally, a SAR should not rely on a single motivation module or a single scheduled time for it. This thesis did not further explore how a SAR can fulfil properly the motivation role, however, from the results presented I argue that more responsiveness and interactive dialogue is likely to improve this. Gamification of exercises was also shown to promote high levels of engagement and motivation in patients. For instance, the Toy Relay activity, an exercise to improve patients' walk, promoted high levels of patient engagement and was identified by therapists as an effective activity. Gamification of exercises has not been thoroughly explored in this thesis, however, it is a well established concept in the Serious Games field [73]. The main purpose of Gamification is to make tedious repetitive exercises enjoyable to encourage patients to do physical activity or physical rehabilitation. The challenge in those systems is to adapt the difficulty level of the task to the patient's capabilities [131]. Most of those systems take advantage of video games [43, 87, 95, 236] or virtual reality devices [31, 121, 194, 228] as discussed in Section 2.1.3. Further work should explore the gamification of existing clinical exercises with the NAO robot, for example, the child competing against the robot, or their best which the robot remembers, in targeted ways to promote specific physical movement, such as holding a pose for a sufficient time.

The incorporation of other disciplines during the development of the robot is also strongly recommended. For example, all robot speech was scripted by physiotherapists or myself, and may be better scripted by play therapy specialists and/or game designers. Such expertise may better target the speech to enhance the robot's motivational and companionship roles.

The personalisation of the session with the robot, accompanying patients through their entire rehabilitation session, was also well received by all the participant groups. This was exemplified in numerous cases by clearly positive reactions from patients when the robot referred to them by name. A more personalised robot is desirable for rapport building and to better suit the patient's needs, however, this is not always feasible. All patients are both unique, and variable in their needs over time, making targeted personalisation of interactions a challenging problem.

Rapport building and personalisation could also be better targeted through interactive voice-based dialogue between robot and patient. However, while advances in natural language processing are clearly enabling this possibility (e.g., Google Assistant, Siri, Alexa, etc.) it was generally observed that state of the art in speech recognition and natural language processing is not yet advanced enough to support ongoing conversation with the robot [170], particularly in the case of children with developing speech [106], or speech impediments related to their presenting condition. Possible pathways for better dialogue include pairing the robot with existing natural language processing APIs such as provided by Google [74]. This, however, must be balanced with the need of robust performance across diverse patients. In some cases, verbal dialogue may not be appropriate, in which case alternative forms of engagement and personalisation may be needed.

While the robot guides patients through whole prescribed programmes of exercise like a coach, it lacks the ability to provide feedback about the patient's performance Patient testing was prioritised over such features in order to determine the relative priority of different features for the development of a SAR for rehabilitation. Phase 2 results indicated that this lack of ability to monitor patient activity and emotional state were key factors in why participant's perceived the robot as lacking responsiveness. Therapists in particular emphasised a high desire for a system that corrects patient technique, adapts to patient mood, and responds to patient questions, none of which was present in the system developed for this thesis. However, I argue that a system enabling such capabilities would likely also require external sensors [78, 79, 177], calibration and/or dedicated room, thus posing other significant challenges for its integration with clinical care in a busy hospital setting. For instance, Phase 3 evaluations, in which parents operated the robot without any technical assistance on-ward, would have been very challenging if the robot required an initial calibration, or a dedicated space. This should not limit researchers developing extra capabilities for their SARs using external sensors, however, the use of external cameras or wearables must be carefully considered in the context of the SAR's intended operation, and with the option to not make use of such features to allow flexible use of the system.

I argue that many of the elicited requirements from this study of SARs in clinical practise will remain the same for other robotic platforms and future technology advances. However, the design decisions may vary depending on the needs of the environment, the needs of the targeted population, and the technology used. This thesis has shown the importance of the determination of key implementation and design decisions through an in situ design process. Developers should elicit their own design decisions considering the needs of their application maximising the fulfilment of the requirements.

8.1.2 Design Process Evaluation

This thesis has presented a design methodology that has progressed the development of a SAR from exploration activities during informal visits to a base-level stand-alone therapeutic aid for rehabilitation, deployed in daily clinical sessions as part of on-ward care delivery. Here I discuss features of this design process, and their impact on both the system developed, and the perceptions of key stakeholders.

Rapport and Trust Building with Stakeholders

Regular frequent in situ engagement with clinical stakeholders has been key to establishing trust and rapport. During Phase 1, therapist attitudes evolved from curious and unconvinced at the beginning, to increasingly interested and engaged in the SAR's development, and the design process. I argue that this in situ design process was essential to the establishment of the SAR as a legitimate and viable therapeutic aid, which in turn established clinical advocates for the SAR. This has been crucial to the recruitment of patients to participate in Phase 2 and Phase 3 testing (Chapter 5, Chapter 6 and Chapter 7), and to the long term support of the project by the rehabilitation clinic.

Phase 1 established researchers' relationship with clinical staff and clinical concepts. The identification of a set of exercises the robot was able to perform, and the clinical knowledge of a group of patients that commonly are prescribed those exercises was key. Defining the target patient population and associated exercise set, in consultation with therapists in Phase 1, allowed therapists to engage more directly with the design process by identifying appropriate patients to focus on, and to recruit for Phase 2 testing. In Phase 2 testing, the patient population broadened to a larger population of children in rehabilitation, suggesting the early focus on one patient cohort did not limit the scalability of the system to other patient groups.

I argue that the design of SARs for other health care applications may benefit from a similar design process of initial in situ exploration and stake-holder relationship building, leading then to the focussed development of a viable prototype for feasibility and technical capacity testing in Phase 2. I further advocate for a focus on discrete goals for the system rather than developing advanced systems requiring long periods of research, implementation and testing. In our experience, discreet modest goals allowed therapists to engage more readily with the process. Early Phase 1 attempts to present and demonstrate the general capabilities of the NAO system to therapists produced few outcomes, with no clear link to its practical implementation and therapeutic value.

Building Familiarity through Experience

The design process has provided therapists with direct access to the SAR system, allowing both hands-on experience manipulating robot limbs, but also with the software interface. While in general, health professionals do not have the time (and perhaps interest) in this level of access, our experience has been that physiotherapists generally take up the opportunity, when offered, to explore the SAR's capabilities. This was observed to increase familiarity with the SAR's capabilities (and limitations), but more importantly, provided an entry point for care-givers to directly contribute to the requirements analysis and design of the SAR. Whether the level of engagement I experienced is specific to physiotherapists, or to the particular clinic is unclear. I argue, however, that providing frequent opportunities for stakeholders to engage with such novel and unfamiliar technology promotes transparency in the design process, and a sense of ownership of the deployed system. This is a crucial feature of any design process that seeks to deploy SAR's in a health care setting, where preconceptions and a lack of familiarity and trust of the technology (and the design process) risks impeding confidence and acceptance.

Limitations of the Design Process

Certain limitations should be considered when designing in situ: regular on-site visitation requires large time investment of a small, dedicated technical development team. Requirement elicitation and design decisions require this necessary time investment. Our approach promotes design and integration of a SAR into clinical practise but is not conducive to technical innovation by a small development team. With more resources, parallel lab-based development could be informed by, and feed into Phase 2 prototype testing. Stakeholders' expectations must also be managed. While in situ development promotes design transparency, it also exposes delays and system failures directly to end-users. It is thus important to establish a common understanding of the constraints and limitations on both the system, and the development cycle.

In-situ design in a health care setting must carefully manage all the above considerations within the context of a highly demanding and busy clinical environment. Technical developers must always concede to the needs of patients and therapists, which may often mean little progress is made in an individual clinic visit. High frequency visitation can mitigate this, increasing opportunities for engagement with health care professionals, as well as their familiarity and acceptance of the technical development team.

8.1.3 Acceptance Evaluation of a Robot with Limited Capabilities

An in situ, in the wild evaluation of the SAR prototype's acceptance has been presented in this thesis. For this, a deliberately minimal system has been evaluated to determine what impact a system like this has on care delivery, and to ascertain a clear set of priorities for future development. Table 8.1 presents the current limitations affecting the roles of our SAR. These limitations are supported by both Acceptance questionnaire data over sustained periods of deployment, subsequent interviews and Phase 3 data. Through these phases of evaluation, I argue that this thesis represents the most thorough user-study of a SAR in the rehabilitation context, from which clear points of focus for future development can be drawn.

Overall, Phase 2's Acceptance Evaluation supports wide acceptance of the developed prototype by all participant groups. This is despite reported limitations such as the lack of responsiveness to the patient's mood, or the robot not being able to hold a conversation. This suggests that focusing on operation aspects for the development of a viable prototype for ongoing clinical deployment is also beneficial, and can compensate for limited artificial intelligence capabilities. Increasing the level of responsiveness of the robot is also an

Table 8.1: Limitations affecting the roles of the robot.

Issues	**Roles affected**
Incorrect speech recognition	Motivator
Lack of responsiveness or able to hold a conversation	Companion
Lack of responsiveness to the patient's mood	Companion and Coach
Monitor the patient to provide real time feedback	Coach
Exercise demonstration not required for frequent users	Demonstrator and Motivator

important aspect to consider, however, in this thesis I prioritised the development of a minimum viable robot in order to determine its key use cases.

The NAO robot lacks a functional speech recognition module. Nowadays, intelligent virtual assistants (Google Assistant, Siri, Alexa, etc.) are integrated in many devices (e.g., cellphones, home assistants) making them accessible to the general public. Such intelligent virtual assistants are more advanced than the embedded speech recognition module of the NAO robot [170], thus, participants' previous experiences with such technology might have set some expectations that were not met with the SAR. In order to increase the responsiveness or the social presence of the robot, an intelligent virtual assistant needs be integrated into the NAO robot. A part from the pre-programmed speech for the rehabilitation session, the SAR in this context should be able to understand basic commands from the participants such as: *"What did you say?"* or *"Can you repeat the demonstration?"*. Those commands could be triggered under '*'Hey NAO!"*, and the intelligent virtual assistant must have be aware of the rehabilitation context. Without an advance speech recognition module, the SAR risks losing its effectiveness as an engaging, intelligent companion.

State-of-the-art intelligent virtual assistants lack emotional intelligence, providing no ability to perceive the mood of the interlocutor. Providing robots with emotional intelligence thus represents a clear gap in the research. External sensors have been commonly used to provide the robot information about the performance of the patient while doing exercises [78, 79, 177]. However, those systems still do not react according to the patient's mood, for example, a stubborn patient not wanting to finish a set of exercises.

The SAR developed is semi-autonomous, meaning that the robot requires the assistance of a human to overcome certain hardware limitations and proceed with the session. This kind of symbiotic human-robot interaction has been previously explored with a mobile robot guiding visitors [186]. While in some ways a robot requiring assistant is a limitation, it was also observed to facilitate engagement from different participants in the session, and may have indeed enhance patient engagement in their rehabilitation. Whether this is specific for this clinical context, where most of the patients also require help, remains unclear. However, the use of a robot that requires assistance must be carefully considered in the clinical context. For example, some physiotherapists noted a trade-off between having the robot and focussing on the patient.

Our design and evaluation process, in addition to general acceptance, probed deeply into the perceived impact of the SAR's inclusion in therapy sessions. Combining observational data from Phase 2 with post Phase 2 interviews provided a thorough profile of how the robot's inclusion, its shortcomings, and overall design choices (including its roles) impacted how therapists themselves delivered care. Acceptance questionnaires highlighted Perceived Ease of Use (PEOU) and Perceived Usefulness (PU) as overwhelmingly positive, however, open feedback and interviews alluded to issues that arose. This would not have been apparent without our in-situ evaluation and follow up study.

After the first, second, or third use, participants found the robot useful for its purposes, and easy to use despite having limited training and exposure to the system. A focussed training session would benefit participants to operate the robot independently. However, a self contained robot able to give instructions with respect to failure recovery, and able to cue the operator appropriately, can provide users more confidence when using it, even without training. A prototype with such capabilities promotes ready use of the system with minimal time cost and overheads, ultimately leading to more user data for testing and improving the system. Multiple uses and experience with the robot has also been shown to increase the perceived ease of use of the system.

8.1.4 In Situ Evaluation Recommendations

The iterative development and evaluation of the prototype ran for almost 3 years, a large period of time for a study of this kind. Researchers seeking to do a similar in situ evaluation study in similar settings should consider the following:

- Patient recruitment and scheduling is a complex and on-going need for such studies. Having someone on the research team with access to the patient details, including prescribed rehabilitation programmes and schedules is highly beneficial to research planning. If not possible, researchers should maximise availability in their timetable to take advantage of any possible participant who may become available at short notice.
- In situ evaluations such as those presented in this thesis must necessarily take full advantage of evaluation opportunities as they present themselves. It would be therefore advantageous if multiple different research questions can be simultaneously addressed within the same experimental protocol, facilitated by different researchers focusing on different aspects of the human-robot interaction. However, this approach

can be more challenging if conducted in the context of an iterative design process such as presented in Phase 2. Researchers also should bear in mind that patients and their treatment are the priority in such settings, so studies should not be too overwhelming or burdensome for participants.

The exploratory phase of the SAR, conducted prior to the work of this thesis, was deliberately unstructured. Wizard-of-Oz control was allowed, and possible malfunctions with the robot were expected. However, during the evaluation of the prototype in Phase 2 and 3, where the robot led and guided patients though their rehabilitation session, malfunctions of the robot could cause major disruptions in the rehabilitation session. This put researchers under pressure when the session was not going according to plan, sometimes increasing their levels of anxiety. Such events normally occurred at the beginning of sessions when establishing the network with the robot and the laptop, or during posture transitions of the robot. Therefore, researchers doing experiments, or evaluation of prototypes in such busy environments would benefit from allocating enough time at the start of the session to test the set up, and have alternatives to continue the session in case of a robot malfunction.

In line with Bers et al. [11], a multidisciplinary team working in a hospital environment can expose members of the research team to the hospital reality and impact them emotionally. For instance, researchers who are not used to working with patients with severe medical conditions. While this is expected in a hospital setting, and indeed in a paediatric rehabilitation clinic, there is potential benefit in research team members being informed beforehand of the specific medical condition of the patient that will participate in the study.

Working with inpatient children can also be very rewarding. Patients with long stays in the hospital can be exhausted by the repetitive routines, so a novel device that accompanies them in their rehabilitation can also provide rewarding positive experiences. Patients who in general dislike the robot provide new insights of improvement to the research team.

8.1.5 Metrics to Evaluate On-Ward Integration

Different phases of the project evaluated different aspects of the SAR. During the acceptance evaluation of the robot (Phase 2), I used common validated metrics from the Human-Robot Interaction literature in order to evaluate the users' perceptions of the robot [8, 85]. Phase 3 required different metrics in order to measure the integration of the robot into existing clinical practice. Due to the lack of similar work in the literature, I derived a list of observable items from interviews with physiotherapists.

The derivation of these observable items provided an in-depth breakdown of what therapists look when assessing the quality of a session, thus also providing a base for assessment. Notably, the application of these metrics in the Phase 3 study did present challenges not experienced in Phase 2 evaluations. For example, some aspects of the care delivery such as exercise technique or the nuances of patient mood were not adequately captured compared to less complex observations such as exercise compliance using the observable items provided. I therefore regard these observable metrics as preliminary, with further research required to better target key components of a SAR's integration in clinical care. I argue, however, that the process of deriving this Objective Structured Assessment through physiotherapist interviews has been invaluable to understanding the key qualities sought in a session, providing guidance for future development of SAR's for this purpose.

8.1.6 Socially Assistive Robot Integration

Phase 3 was a deliberately designed phase to explore issues related to the SAR's integration in multi-day single patient use cases. The closest related work in the literature explored the use of a storytelling robot for inpatients at the Boston's Children's Hospital [11]. The authors reported some challenges I also faced when using robots on the ward such as: session scheduling complexities; security breaches when using robots in public spaces; or the requirement of a system that allows interruptions.

The presented case studies in this thesis brought new insights into the on-going deployment of the prototype in the hospital, in order to be operated by carers without any technical support. More importantly, however, this study highlighted key considerations for the integration of SAR's in busy hospital settings generally. From a design perspective, Phase 3 highlighted the need for technology developers to be prepared to modify and adapt their prototypes according to the new lessons learned. In some cases, integration testing may highlight requirements in conflict with previous considerations, thus, developers can allow different functionality options if possible, or implement the most suitable for their final scenario. Examples of design decisions that changed from weekly use of the robot (Phase 2) to daily use (Phase 3) were: the demonstrator role of the robot which became less relevant when in daily use; or the introductory speech of the robot, used to create rapport with the patient, became less important the last days of the week. Such findings highlighted the time varying nature of the SAR's roles in the session, dependant on the changing needs of the patient. Other factors not experienced in Phase 2 but prominent when tested in the less controlled on-ward setting were external distractions and disruptions; all common place in a typical hospital ward. Designing SAR to work effectively in such settings is critical to its ultimate acceptance, yet was not made evident until such testing was performed.

The ultimate way to evaluate the integration of the prototype on the ward is to monitor the long term use of the robot in the clinical setting. In this thesis, the closest scenario has been to evaluate how well parents can deliver therapy in its intended place of use: on the ward, without physiotherapist or technical supervision.

The Phase 3 case studies were deliberately ambitious and the most challenging experiments undertaken in this thesis due to the number of sessions scheduled per week, and the required coordination between participants and researchers. For example, sessions where a therapist was required to attend (to evaluate the technique of the exercises) were the most challenging to schedule. Such studies may benefit from having a clinical researcher dedicated to patient recruitment, delivery of the SAR to patient wards, and sessions observation.

Overall, the robot has been tested delivering more than 60 rehabilitation sessions across two phases of development and evaluation. This testing has thoroughly examined the performance of the prototype system, and guided its iterative development. What is made clear is that while SAR system's such as this may be improved and further developed, busy hospital setting will always present external factors and unpredictable scenarios. Incorporating such knowledge into the design process is critical, and in general, preferable to any attempts to try and control the environment to meet the needs of the SAR. Thus, providing alternative operating modalities for the SAR should be a high priority. This may include varying use cases, or limiting its use to certain exercises or activities, or simply deploying it as a comforting presence in the room, thereby limiting its use in roles such as demonstration or coach. This multi-faceted evaluation has provides insights that can inform such design decisions for other rehabilitation contexts, and other clinical applications of SARs.

8.2 Specific Recommendations for Socially Assistive Robots in Paediatric Health Care

In this section we compile all the learnings derived from this thesis for the design of SARs in paediatric health care settings.

Software Design - Configurability

- A SAR system must allow to be configured by non-technical users, such as physiotherapists, selecting the required rehabilitation session parameters.

- Other carers, such as parents, should be able to initialise, pause, resume, cancel the scheduled rehabilitation session.

- Parents should be allowed to reconfigure the set of exercises to be executed within certain blocks, and should be able resume the session from any exercise in case of session aborted.
- Parents should also be allowed to modify certain parameters before starting the session such as carer name, and alter the speed of the exercises in execution time if required.
- Some patients highly value the robot being personalised for them such as mentioning their name. Thus, SARs should include a vast range of parameters to personalise the system.

Software Design - Instructions

- The SAR should provide enough clear instructions in order to be used by carers without previous training. Visual and verbal cues can be used to prompt appropriately the user.
- The SAR also has to provide as much information as possible such as the exercises to be done in the session, and the number of sets and repetitions before starting the exercise.
- Demonstration of the exercises are important so patients and carers can visualise the exercise to be done. However, experienced patients might not require the demonstration; thus, exercise demonstration should also be configurable. Alternatively, previous interactions with the robot should be stored in a data base and the robot should behave accordingly.
- Reminders to correct the technique of each exercise should be provided by the SAR, also the SAR should remind patients to follow its pace.

Software Design - Interaction

- The SAR should have interactive modules throughout the session in order to keep the patient engaged.
- Repetitive speech can negatively affect participants perceptions of the robot. Thus, the robot should provide a vast range of short utterances.
- The current speech recognition module of the NAO robot is not functional for paediatric health care. Thus, alternatives should be considered, for instance the integration of an intelligent virtual assistant.

- If the SAR is intended to be used with multiple patients at once, the SAR should be personalised for all patients and needs to coordinate the interaction among them.
- A SAR that needs some assistance can increase the level of interaction and participation of patients in the rehabilitation session, for instance tapping the robot's head to proceed with the exercises.
- SARs should be responsive and react to the patient's mood, however, this is one of the biggest challenges of the human-robot interaction field.

Hardware Issues

- Some participants, most predominantly adults, associate the colour of the robot to a specific gender. Those participants might prefer a robot that matches the gender of their child. Neutral gender colours could be used in order to mitigate such issues.
- Back-to-back sessions can drain the battery of the robot, the server, or the tablet. Sessions should be scheduled with enough time to recharge batteries unless multiple devices can be used.
- Repeated rehabilitation movements tend to overheat the motors of the NAO robot. Overheated motors will increase the chances of failure when changing posture such as standing up. Thus, monitoring the heat of the motors, and providing alternatives when changing postures should be considered.

Study Design - In Situ Issues

- Technical failures can be very frustrating for all participants. Children might become stubborn and decide to not do the exercises without the robot. Carers might spend precious rehabilitation time trying to fix the robot.
- Carers might perceive the SAR as expensive, as a result, they might dedicate more time to the robot than the patient trying to prevent any possible errors.
- Patients engaged with the robot might demand less attention from carers during the session.
- Passwords of the devices such as the tablet interface and the server should be different to prevent unauthorised access.
- The volume of the SAR must be easily controlled during execution time to avoid disrupting other families on the ward.

Study Design - Methodology

- Technical developers must always concede to the needs of patients and therapists, which may often mean little progress is made in an individual clinic visit.
- If intending to use a SAR multiple times with a patient, exploratory phase studies should also consider sessions with the same patient during multiple interactions. Observations from the latest sessions might be different and will bring different learnings for long term use of SARs.
- Even though a SAR is developed to be used without any prior training, training should be considered because it promotes participants' confidence, and can reduce the negative impact of the robot in rehabilitation such as errors and anxiety.
- Scheduling rehabilitation sessions with the SAR in a busy paediatric hospital could be very challenging. It requires to find a time slot that fits the patient (who has a different activities in the hospital) with their carers, researchers, and physiotherapists. Having a researcher hosted in the hospital with access to new patients and their schedules might ease this task.
- Running rehabilitation sessions in the patient's room facilitates the scheduling of the session not requiring to book a treatment room. It also prevents external distractions in case that a session needs to run in a common area such as the gym.
- Sessions on the patient's room will have interruptions (lunch, afternoon tea, nurses, doctors, etc.). The SAR should be able to handle those interruptions.

Study Design - Data Collection

- Collecting data in private environments such as hospital rooms is challenging if researchers intend to not be present in the study. Self-report measures and logfiles of the robot are some of the methods researchers can use to collect data without interfering in private environments.
- Self-report measures should be collected systematically to prevent surveys from being lost or not completed.
- Researchers collecting observational data should be very familiar with the form in order to not waste time when searching for items. The form should be designed to follow sequentially the exercises of the session.

8.3 Summary of Contributions

This thesis has explored the development of a SAR for paediatric rehabilitation in the context of ongoing clinical deployment. Firstly, this work was contextualised in the busy hospital setting of the Royal Children's Hospital Melbourne paediatric rehabilitation clinic, where each year, over 1,000 children suffering from mobility impairments undergo intensive rehabilitation programmes. Patient's motivation and adherence to their prescribed programme of rehabilitation exercises are key challenges faced when working with young paediatric rehabilitation patients, and can be stressful and emotionally draining experience for children and their families.

Different technology devices such as video games or virtual reality have been used to increase patients' motivation in rehabilitation, however, these technologies have not seen wide adoption in clinical care. SARs offer a versatility of use cases like no other for rehabilitation, offering functionality that can: provide a social companion role with its physical presence and social interaction, serve as a proxy to therapists when not available, while also involving carers and parents in their child's rehabilitation, as a social mediator, providing support to patients and carers in their different roles during the rehabilitation. Below I outline the key contributions of this thesis by addressing each research question this thesis aimed to address.

New Insights for On-Going Clinical Deployment of SARs

Previous work has reported potential benefits for motivating patients in physical rehabilitation using SARs [67, 132, 143, 213, 235]. Chapter 2 of this thesis reviewed how such devices have interacted with the paediatric population in health care settings, identifying the primary research question addressed in this thesis (RQ1):

> *What roles and operational requirements must a socially assistive robot fulfil to perform effectively as a rehabilitation aid in on-going clinical deployment?*

This thesis has extensively explored how a SAR can be applied in paediatric rehabilitation. Data gathered over different phases of this study have provided new insights into roles previously proposed, but until now, not properly examined. In terms of roles for SARs in rehabilitation, this thesis has shown that Motivator and Demonstrator roles are most strongly supported. However, the relative importance of such roles can change over multiple uses. SAR roles should therefore be configurable and adaptable to the patient's needs and context of the prescribed rehabilitation programmes. The bidirectional interaction between robot and patient is a key component for the motivation role of the robot; however, the advances in speech recognition and natural language processing in the robotic platform still cannot support ongoing conversation with the robot [106, 170], posing challenges for the design of such roles.

This thesis has clearly demonstrated the impact of system errors (both hardware and software) on user acceptance and trust. This presents a significant challenge for the integration of robotic systems, where system errors and failures are common place, even amongst high-end commercially available robotic systems [51]. This thesis has demonstrated the importance of conservative design decisions to mitigate risks, and emphasise robust performance. This comes at the cost of some desirable features, but ultimately, the findings of this thesis support the usefulness and general acceptance of the SAR despite these short comings.

A Novel Design Process for SARs in Health Care Settings

I have presented a novel, three-phase in situ design process for SARs in clinical settings. The design approach presented in this thesis emphasises the deployment of the robot in the intended place of use with its final users. It is composed of three phases: an exploratory phase to elicit a basic set of roles and requirements; a prototype iterative development phase; and an ongoing use phase. In evaluating this design approach I addressed the following research questions (RQ2 and RQ3):

> *What are the advantages and disadvantages of an in situ design process when designing and evaluating a socially assistive robot for use in health care settings?*
>
> *How can an in situ design process for socially assistive robots be effectively implemented in a busy health care setting?*

The three-phase design and evaluation process, emphasising frequent stakeholder engagement and research development, embedded in the context of the system's intended operation. I have argued that this process has facilitated the most comprehensive examination of SAR's for rehabilitation to date, providing different perspectives of the system's performance, its acceptance by stakeholders, and its integration into on-ward clinical care. A clear benefit of the design approach has been the ability to engage and test ideas with patients early in the process, and then regularly and frequently as the iterative design process evolved. Rapport building and familiarity with clinicians has also been a critical outcome of this process, facilitating on-going opportunities to test and evaluate through trust and over time, a common understanding of the project's aims, and the clinical context. However, the design approach also requires large time investment, and exposes deficits and errors of the system to intended final users. This affects negatively clinicians' impressions of the system for future use, potentially influencing perception thereafter. The proposed methodology would benefit from extending the evaluation to other clinical sites performing the same tasks to ensure generality and scalability of the developed system.

New Insights into Acceptance of SARs for Rehabilitation

I have reported on the iterative development of the prototype based on researchers' observations and participants' feedback. This was done together with a formal evaluation of key stakeholder perceptions of the prototype SAR delivering paediatric rehabilitation. In consultation with therapists, the prototype was designed to guide patients through their entire rehabilitation programme, semi-autonomously, under the guidance of an adult carer. Through this, I addressed the following research question (RQ4):

> *What factors impact the acceptance and attitudes towards socially assistive robots designed to guide paediatric rehabilitation sessions?*

I explored the SAR's acceptance by parents, patients and therapists. Results indicated that the system's usability, configurability, and ability to physically demonstrate exercises were factors that most strongly influenced perceptions of the robot's usefulness and users' perceptions of competency when using the system. Robustness and reliability are key factors for the acceptance of SAR's in such settings. It was also well established that therapists are the key stakeholders, and their impressions ultimately dictate the uptake of the technology.

From question RQ4, two sub questions (RQ4.A and RQ4.B) were also addressed:

> *How do these attitudes change with experience?*

Repeated use of the SAR over multiple sessions impacts user perceptions of the system. The results presented in this thesis support a paradigm of providing initial operational training to use the SAR, focussing primarily on what issues may arise, coupled with immediate and frequent opportunities to use the SAR as part of the delivery. This is supported by data presented in this thesis, consistently showing increasingly positive responses to questions of perceived usefulness, its perceived usability and levels of anxiety experienced when using it. Underpinning this, however, is a robust system and/or sufficient training and resources to identify issues and rectify them. This thesis has further shown that making the SAR readily available to caregivers, without the need for engineering support or complicated setup, supports its wider use under more authentic conditions, thereby allowing caregivers to build experience and familiarity with the system.

> *How do these attitudes differ between therapists, patients, and their parents/guardians?*

Therapists hold the duty of care for their patients, and are also extremely busy in such clinical settings. This thesis has shown that the SAR must be perceived to be useful to their needs, and be easily integrated into their daily work patterns to be accepted as an effective therapeutic aid. In situ design has facilitated the design of a system that has largely achieved this. Patients' attitudes towards the robot were different depending on their personality, however, our results indicate children in general expressed more positive attitudes than adolescents. Parents were the most positive participants on the use of the SAR to deliver rehabilitation to their child, often motivated by a desire to find different, more effective solutions to lessen the burden of rehabilitation on both their child, and themselves.

New Metrics for Evaluating the Quality of Care Delivered with a SAR

After the iterative in situ development and evaluation of the prototype SAR, Phase 3 of our design process sought to evaluate the integration of the prototype into on-ward care. The evaluation of the integration of the robot on the clinical ward motivated the research question (RQ5):

> *Upon what metrics can we evaluate the success of a socially assistive robot in delivering rehabilitation therapy without physiotherapist supervision?*

This thesis presented preliminary work towards developing observable metrics for assessing the quality of care delivered with a SAR when a therapist is not present. The metrics to evaluate the SAR's integration were derived from semi-structured interviews with physiotherapists that previously participated in the formal evaluation of the robot prototype. Establishing these metrics through physiotherapist interviews provided a highly detailed understanding of how therapists assess the success of a session. The use of the list of observable items during Phase 3, indicated there still remains challenges for how these metrics can be utilised to assess SAR care delivery, However, the observable items provide a basis for understanding what outcomes SAR's must target.

New Insights into Factors Impacting the Integration of SAR's into Daily Clinical Use

The primary use case motivating the research presented in this thesis is the on-ward deployment of a SAR for therapy sessions without an attending physiotherapist. To this end, and in line with the third phase of my proposed design process, I addressed the following research question (RQ6):

> *What factors impact the integration of a socially assistive robot into daily, on-going use in hospital setting?*

Through a pilot study, and three formal case studies, I presented a novel evaluation of a SAR when deployed in daily use with individual patients. This study examined a week of care delivery using the SAR, in which the therapist and engineer were removed after the first sessions. This authentic in the wild evaluation uncovered a number of factors to consider for the design and integration of SARs in health care. Configurability and adaptability to the changing needs and context were chief amongst these findings, as well as designing for the high likelihood of external interruptions and distractions. Such environmental factors present challenges for systems that attempt to incorporate sophisticated natural language processing or motion analysis using on-board sensors. Current state-of-the-art for such technologies would likely require a dedicated space, and external sensing. Such options may be available in some clinical settings, but was not compatible with the integration of the SAR into the clinical setting described in this thesis. Such findings make clear the value of in situ development and integration testing of SARs.

Finally, by applying the metrics derived from Chapter 6, Phase 3 case studies were also used to address the final research question of this thesis (RQ7):

> *What factors impact the quality of rehabilitation care delivered using a socially assistive robot when a physiotherapist is not present?*

Case studies with inpatients spanning one week each were used to apply an Objective Structured Assessment or using metrics derived from therapist interviews in Chapter 6. The case studies provided new insights, not reported in the previous phases neither in previous studies, for the integration of the robot on the ward. The lessons learned from the case studies will guide the last robot improvements before a future clinical trial.

Case studies observations indicated that patient's mood, compliance or concentration can be negatively impacted if the SAR is not personalised correctly for the session, such as the robot mentioning correctly patient's or parent's name. Other issues impacting participant's concentration were long waiting periods, or robot demonstrations for patients who were already familiar with the exercises. Robot malfunctions such as falls or long waiting periods can also impact emotionally patients who interact in daily basis.

8.4 Limitations of Study

This thesis developed a prototype with one particular hardware platform: the NAO robot. While it is expected the design process translates to other robotic platforms, this thesis did not explore this. Other robotic platforms may have facilitated different sensing options, different stability challenges, or other motors' performance which may impact how the robot is applied.

The studies presented in this thesis were conducted in one particular hospital, thus, the findings reported cannot be conclusively generalisable to other clinical settings. However, I argue that the variability of settings and context explored within the hospital make a strong case for the generality of outcomes reported here; however further trials in other settings are needed to confirm this.

Recruitment of study participants has been unavoidably biased towards patients judged by their therapist to possibly benefit from use of the SAR. This was a necessary compromise to implement the in situ evaluation, but may have caused some bias towards positive responses. Experiences of patients and families that chose not to participate may have provided additional insights not captured in this thesis. However, it is likely that in the context of clinical deployment, as with any therapeutic aid, similar criteria to this study would be applied by therapists to determine whether to include such a technology.

The limited number of available therapists to participate in this thesis was a practical limitation dictated by therapist availability, and their roster. However, therapists recruited span a range of experience levels. The inclusion of more therapists would likely uncover further findings not reported in this thesis.

Data collection also presented its limitations due to the nature of the studies. Young patients or patients not cognitively able did not provide survey responses. The presence of researchers when collecting observational data might have influenced the participants' behaviour, video recording was not an option due to logistics and ethics. Robot logs only report the exercises executed by the robot, but not the patient.

8.5 Future Work

The main focus of this thesis has been on the development of the robot to be used on the hospital ward. Outpatients can also benefit from our SAR, however, patients using the robot at their home is a remaining scenario not tested yet. There are still some open research questions such as: are there any other roles or requirements for a SAR to deliver rehabilitation at home? Which are the main differences between a SAR for paediatric rehabilitation in a hospital and at home? Is the robot a beneficial therapeutic aid if used at patient's home?

The SAR has been perceived very useful for its purposes when used in a weekly basis. Due to the limited number of sessions with the SAR per patient, I could not analyse the effect of the long term exposure of the robot, which diminishes the novelty of the SAR. This study, however, could naturally be extended through a longer term evaluation of the system to gain a better understanding of this effect. Diminished novelty of the system is of course inevitable, but how the system can be designed to maintain patient engagement once the novelty effect has subsided presents interesting questions for SAR design. In the rehabilitation context, variations between sessions, along with built in adaptations to the patient, may be explored further to enhance the SARs companionship role.

The main aspect missing in our prototype, which has been reported by the participants, has been the lack of responsiveness of the robot to the patient's mood, or to provide feedback about the patient's performance. Underpinning these highly desirable features are key research questions in the human-robot interaction field. Robust natural language processing, emotion recognition, human motion analysis are all clear open areas of research, and highly relevant to the development of SARs for rehabilitation. This thesis has made clear these as priorities, and future work will explore how such capabilities can be integrated with the system, while also maintaining critical operational requirements.

This thesis did not consider the hardware design of a social rehabilitation robot. The NAO robot, being a widely available, general purpose social robot, was adapted to the needs of rehabilitation through software choices. A key question for future research is to consider how the hardware components may better serve these needs. Limitations imposed by a system such as NAO may be overcome through a ground-up SAR design targeting the needs of paediatric care. This questions spans both from factor and external surface materials, as well as motors, sensors, and their positioning. The design process and findings of this thesis provide a solid foundation for developing novel, built-for-purpose social robots for paediatric rehabilitation.

This thesis has described the deployment of a SAR to deliver paediatric rehabilitation. The prototype has been evaluated across different studies from which the SAR has been developed into a clinically deployable aid. The most critical future work to be conducted is a randomised controlled clinical trial (RCT) of this technology. This thesis has not evaluated clinical benefits of the system, and in general, this remains an open question for SARs in rehabilitation contexts. Benefits may include rehabilitation outcomes such as less time spent in hospital or improved movement/strength, but may also include improved emotional wellbeing during rehabilitation. These are clinical questions that can only be addressed though an RCT.

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Appendices

Appendix A

Phase 2 Sessions Summarised

This appendix includes Table A.1 which provides a structured overview of the 41 rehabilitation sessions during Phase 2 study. The table indicates which exercises were performed, the duration of each session, exercises completed, and any system disruptions that may have occurred.

Table A.1: Phase 2 rehabilitation sessions summarised. Forty-one sessions, and twenty different patients. The exercises programmed were chosen by the patient's physiotherapist. Duration of the rehabilitation session from the introductory speech to the farewell dance routine or the session was halted (mm:ss format). System disruptions during the session, Version of the socially assistive robot

No	Patient	Ex. Programmed	Ex. Completed	Duration	System Disruptions	Comments	Version
1	P-1	Static Quads Hip Abd. Laying Toy Relay	Static Quads Hip Abd. Laying Toy Relay	16:19		Patient expressed positive attitudes towards the robot, enjoyment and excitement.	V0.5.0
2	P-1	Static Quads Quads over Roll Leg Raises Toy Relay	Static Quads Quads over Roll Leg Raises Toy Relay	24:52		Patient showed focus on the robot. Patient happy to do another session.	V0.6.0
3	P-1	Static Quads Quads over Roll Leg Raises Toy Relay	Static Quads Quads over Roll Leg Raises Toy Relay	25:42		Patient expressed positive attitudes towards the robot, smiled and interacted with robot.	V0.6.0
4	P-2	Sit-to-Stands Toy Relay		N/A		Session aborted. Patient non-compliant in therapy sessions.	V0.7.0
5	P-3	Static Quads Quads over Roll Bridge Hip Abd. Laying Hip Knee Flex. S. Sit-to-Stands	Static Quads Quads over Roll Bridge Hip Abd. Laying Hip Knee Flex. S. Sit-to-Stands	31:35	Battery drainage. Engineer intervention was required to restart the system.	Teenager patient did the session on her own, physiotherapist helped at the beginning.	V0.7.0

6	P-4	Static Quads Bridge Hip Abd. Laying Hip Knee Flex. S. Sit-to-Stands	Static Quads Bridge Hip Abd. Laying Hip Knee Flex. S. Sit-to-Stands	22:47	Engineer intervention was required to change the speed of Hip Knee Flex. S.	Patient expressed positive attitudes towards the robot, enjoyment and excitement.	V0.7.0
7	P-5	Quads over Roll Single Bridge Hip Abd. Laying Sit-to-Stands Toy Relay	Quads over Roll Single Bridge Hip Abd. Laying Sit-to-Stands Toy Relay	37:03	Engineer intervention was required to change the speed of Single Bridge. Robot fell when standing up, but no intervention needed.	Patient proactively helped the robot when required. The patient did not like the robot.	V0.7.0
8	P-6	Static Quads Quads over Roll Bridge Hip Knee Flex. S. Hip Knee Flex. L. Sit-to-Stands	Static Quads Quads over Roll Bridge Hip Knee Flex. S. Hip Knee Flex. L. Sit-to-Stands	46:31	Engineer intervention was required due to a Robot fell when standing up.	Patient proactively helped the robot when required. Patient expressed positive attitudes towards the robot, enjoyment and excitement.	V0.7.1
9	P-7	Quads over Roll Single Bridge Hip Abd. on Side Sit-to-Stands	Quads over Roll Single Bridge Hip Abd. on Side Sit-to-Stands	25:25		Teenager patient liked the experience, but preferred to do rehabilitation with a physiotherapist to have a proper conversation.	V0.7.2
10	P-4	Static Quads Bridge Hip Abd. Laying Hip Knee Flex. S. Sit-to-Stands	Static Quads Bridge Hip Abd. Laying Hip Knee Flex. S. Sit-to-Stands	31:34	Engineer intervention was required due to wrong session configuration.		V0.7.2
11	P-8	Static Quads Quads over Roll Hip Knee Flex. S.	Static Quads Quads over Roll Hip Knee Flex. S.	26:02		Teenager patient preferred to do rehabilitation with a physiotherapist.	V0.7.3
12	P-9	Quads over Roll Bridge Sit-to-Stands Toy Relay	Quads over Roll Bridge Sit-to-Stands Toy Relay	19:47		When not distracted, the patient showed focus on the robot and willingness to interact.	V0.7.3
13	P-4	Static Quads Bridge Hip Abd. Laying Hip Knee Flex. S. Sit-to-Stands	Static Quads Bridge Hip Abd. Laying Hip Knee Flex. S. Sit-to-Stands	30:28		Patient expressed positive attitudes towards the robot such as enjoyment.	V0.7.3
14	P-9	Quads over Roll Bridge Sit-to-Stands Toy Relay	Quads over Roll Bridge Sit-to-Stands Toy Relay	18:34	During the Toy Relay the patient stumbled against the robot, engineer intervention was required to recover the system.	Patient expressed positive attitudes towards the robot, smiled and interacted with robot.	V0.8.0
15	P-9	Quads over Roll Bridge Sit-to-Stands Toy Relay	Quads over Roll Bridge Sit-to-Stands Toy Relay	15:54		Patient expressed positive attitudes towards the robot such as enjoyment and willingness to interact.	V0.9.0
16	P-10	Bridge Hip Abd. Laying Hip Knee Flex. L. Sit-to-Stands	Bridge Hip Abd. Laying Hip Knee Flex. L. Sit-to-Stands	28:33		Patient expressed positive attitudes towards the robot, enjoyment and willingness to communicate.	V0.9.0
17	P-10	Bridge Hip Abd. Laying Hip Knee Flex. L.	Bridge Hip Abd. Laying Hip Knee Flex. L.	19:23	Robot fell when trying to stand-up, second attempt was successful. No technical intervention required.	Patient showed focus on the robot. Patient happy to do another session.	V0.9.0
18	P-10	Bridge Hip Abd. Laying Hip Knee Flex. L. Toy Relay	Bridge Hip Abd. Laying Hip Knee Flex. L. Toy Relay	22:24		Patient showed focus on the robot, and expressed positive attitudes towards the robot.	V0.9.0
19	P-11	Static Quads Quads over Roll Bridge Hip Abd. Laying	Static Quads Quads over Roll Bridge Hip Abd. Laying	25:50	Robot fell when trying to stand-up, second attempt was successful. No technical intervention required.	Patient initially seemed sceptical towards the robot, expressed positive attitudes such as excitement and willingness to interact.	V0.9.1
20	P-11	Static Quads Quads over Roll Bridge Hip Abd. Laying	Static Quads Quads over Roll Bridge Hip Abd. Laying	20:25		Patient showed focus on the robot, happy to do another session.	V0.9.1

21	P-11	Static Quads Quads over Roll Bridge Hip Abd. Laying	Static Quads Quads over Roll Bridge Hip Abd. Laying	23:39	Robot fell when trying to stand-up, second attempt was successful. No technical intervention required.	Patient showed focus on the robot, and followed the robot's pace.	V0.9.1
22	P-12	Static Quads Hip Abd. Laying Hip Knee Flex. S.	Static Quads Hip Abd. Laying Hip Knee Flex. S.	16:34		Patient showed focus on the robot, and followed the robot's pace.	V0.9.1
23	P-12	Static Quads Hip Abd. Laying Hip Knee Flex. S. Sit-to-Stands Toy Relay	Static Quads Hip Abd. Laying Hip Knee Flex. S. Sit-to-Stands	32:35	Battery drainage during the Toy Relay. Engineer intervention was required to restart the system.	Patient showed focus on the robot and expressed positive attitudes: enjoyment and laughing. Patient's frustration during the Toy Relay halted the session.	V0.9.1
24	P-13	Static Quads Quads over Roll Bridge Hip Knee Flex. S. Sit-to-Stands	Static Quads Quads over Roll Bridge Hip Knee Flex. S. Sit-to-Stands	20:56		Patient expressed positive attitudes, showed focus, and willingness to interact.	V0.9.1
25	P-13	Static Quads Quads over Roll Bridge Hip Knee Flex. S. Sit-to-Stands	Static Quads Quads over Roll Bridge Hip Knee Flex. S. Sit-to-Stands	20:03		Patient expressed positive attitudes such enjoyment, showed focus, and willingness to interact.	V0.9.2
26	P-14	Quads over Roll Hip Abd. Laying Hip Knee Flex. L. Leg Raises Sit-to-Stands	Quads over Roll Hip Abd. Laying Hip Knee Flex. L. Leg Raises Sit-to-Stands	25:29		Patient expressed positive attitudes such enjoyment, showed focus, and willingness to interact.	V0.9.2
27	P-14	Quads over Roll Hip Abd. Laying Hip Knee Flex. L. Leg Raises Sit-to-Stands	Quads over Roll Hip Abd. Laying Hip Knee Flex. L. Leg Raises Sit-to-Stands	24:26	Robot fell when trying to stand-up, second attempt was successful. No technical intervention required.	Teenager patient led the session with the guidance of the robot and the help of the parent. Patient showed focus and positive attitudes towards the robot.	V0.10.0
28	P-13	Static Quads Quads over Roll Bridge Hip Knee Flex. S. Sit-to-Stands Toy Relay	Static Quads Quads over Roll Bridge Hip Knee Flex. S. Sit-to-Stands Toy Relay	29:23	Inexperienced physiotherapist with the robot needed help to start the exercises after the robot laid down.	Patient expressed excitement before starting the session, and showed focus on the robot during the session.	V0.10.0
29	P-15	Single Bridge Hip Abd. on Side Sit-to-Stands Toy Relay	Single Bridge Hip Abd. on Side Sit-to-Stands Toy Relay	28:27		Patient expressed positive attitudes towards the robot, enjoyment, excitement, affection, and willingness to interact.	V0.10.0
30	P-16	Quads over Roll Hip Abd. on Side Hip Knee Flex. L. Toy Relay	Quads over Roll Hip Abd. on Side Hip Knee Flex. L. Toy Relay	21:47		Patient proactively helped the robot when required, expressed positive attitudes towards the robot and willingness to interact.	V0.11.0
31	P-15	Single Bridge Hip Abd. on Side Sit-to-Stands Toy Relay	Sit-to-Stands Toy Relay	42:15		Poor compliance in this session. Patient did few repetitions of Single Bridge and Hip Abd. on Side. Patient only wanted to do the game (Toy Relay).	V0.11.0
32	P-16	Quads over Roll Hip Abd. on Side Hip Knee Flex. L. Sit-to-Stands Toy Relay	Quads over Roll Hip Abd. on Side Hip Knee Flex. L. Sit-to-Stands Toy Relay	28:04		Patient proactively helped the robot when required, expressed positive attitudes towards the robot and willingness to interact.	V0.11.0
33	P-16	Quads over Roll Hip Abd. on Side Hip Knee Flex. L. Sit-to-Stands Toy Relay	Quads over Roll Hip Abd. on Side Hip Knee Flex. L. Sit-to-Stands Toy Relay	23:41		Young patient led the session with the guidance of the robot and the help of the parent. Patient showed focus and positive attitudes towards the robot.	V0.11.1
34	P-17	Quads over Roll Hip Abd. on Side Sit-to-Stands Toy Relay	Quads over Roll Hip Abd. on Side Sit-to-Stands Toy Relay	62:29	Battery drainage. Engineer intervention was required to restart the system.	Patient was stubborn and refused to continue due to a broken bed recliner. However, patient expressed positive attitudes towards the robot and willingness to interact.	V0.11.1

35	P-17	Quads over Roll Hip Abd. Laying Sit-to-Stands Toy Relay	Quads over Roll Hip Abd. Laying Sit-to-Stands Toy Relay	27:41		Patient expressed positive attitudes towards the robot such as enjoyment. Due to a cervical collar the patient complained for not being able to observe the robot while doing exercises.	V0.11.1
36	P-18	Bridge Single Bridge Hip Abd. on Side Hip Knee Flex. L. Leg Raises Sit-to-Stands Toy Relay	Bridge Single Bridge Hip Abd. on Side Hip Knee Flex. L. Leg Raises Sit-to-Stands Toy Relay	42:28	System failure due to motors overheating, engineer intervention was required to restart the system.	Patient showed focus on the robot, expressed positive attitudes towards the robot, enjoyment, excitement, and affection.	V0.12.0
37	P-18	Bridge Single Bridge Hip Abd. on Side Hip Knee Flex. L. Leg Raises Sit-to-Stands Toy Relay	Bridge Single Bridge Hip Abd. on Side Hip Knee Flex. L. Leg Raises Toy Relay	32:08	It seems the robot was in animation mode and generated several system failures. Engineer intervention was required several times.	Patient expressed positive attitudes towards the robot, enjoyment, excitement, and affection.	V0.13.0
38	P-18	Bridge Single Bridge Hip Abd. on Side Hip Knee Flex. L. Sit-to-Stands Toy Relay	Bridge Single Bridge Hip Abd. on Side Hip Knee Flex. L. Sit-to-Stands Toy Relay	32:35		Patient expressed positive attitudes towards the robot, enjoyment, excitement, and affection.	V0.13.0
39	P-19	Quads over Roll Hip Abd. Laying Hip Abd. on Side Hip Knee Flex. L. Sit-to-Stands Toy Relay	Quads over Roll Hip Abd. Laying Hip Abd. on Side Hip Knee Flex. L. Sit-to-Stands Toy Relay	51:05		Patient showed a lot of curiosity about the robot, quizzed the physiotherapists during the entire session.	V0.14.0
40	P-20	Quads over Roll Hip Knee Flex. S	Quads over Roll Hip Knee Flex. S	12:40		Patient showed focus on the robot, and expressed positive attitudes towards the robot such as enjoyment and excitement. Patient also fascinated by the hardware.	V0.14.0
41	P-19	Quads over Roll Hip Abd. Laying Hip Knee Flex. L. Sit-to-Stands Toy Relay	Quads over Roll Hip Abd. Laying Hip Knee Flex. L. Sit-to-Stands Toy Relay	45:22	Engineer intervention was required due to wrong session configuration.	Patient proactively helped the robot when required, expressed positive attitudes towards the robot such as enjoyment	V0.14.0

Appendix B

Ethics

This appendix includes ethics clearance for the research project from both partner institutions:

The Royal Children's Hospital Melbourne Human Research Ethics Committee:
HREC 36128C, page 277.

Swinburne's Human Research Ethics Committee:
SUHREC Project No: 2016/202, page 279.

ETHICS APPROVAL

14 July 2016

Dr Joanna Butchart
Rehabilitation Department
The Royal Children's Hospital

Dear Dr Butchart

Project Title: **Developing a socially assistive humanoid robot as a therapeutic aid for paediatric rehabilitation**

RCH HREC Reference Number: 36128A

I am pleased to advise that the above project has received ethical approval from The Royal Children's Hospital Melbourne Human Research Ethics Committee (HREC).

The HREC confirms that your proposal meets the requirements of the National Statement on Ethical Conduct in Human Research (2007). This HREC is organised and operates in accordance with the National Health and Medical Research Council's (NHMRC) National Statement on Ethical Conduct in Human Research (2007), and all subsequent updates, and in accordance with the Note for Guidance on Good Clinical Practice (CPMP/ICH/135/95), the Health Privacy Principles described in the Health Records Act 2001 (Vic) and Section 95A of the Privacy Act 1988 (and subsequent Guidelines).

HREC Approval Date: 14 July 2016*
Please note the HREC are no longer issuing pre-determined approval periods. Ethical approval is now ongoing, subject to the submission of an annual report on the anniversary of approval.

Participating Sites:
Ethical approval for this project applies at the following sites:

Site Name
• The Royal Children's Hospital, Parkville and Murdoch Childrens Research Institute, Parkville

Approved Documents:
The following documents have been reviewed and approved:

Document	Version	Date
Protocol	2.1	17 June 2016

Conditions of Ethics Approval:
- You are required to submit to the HREC:
    - An Annual Progress Report (that covers all sites listed on approval) for the duration of the project. This report is due on the anniversary of HREC approval. Continuation of ethics approval is contingent on submission of an annual report, due within one month of the approval anniversary. Failure to comply with this requirement may result in suspension of the project by the HREC.
    - A comprehensive Final Report upon completion of the project.
- Submit to the reviewing HREC for approval any proposed amendments to the project including any proposed changes to the Protocol, Participant Information and Consent Form/s and the Investigator Brochure.
- Notify the reviewing HREC of any adverse events that have a material impact on the conduct of the research in accordance with the NHMRC Position Statement: *Monitoring and reporting of safety for clinical trials involving therapeutic products May 2009*.

- Notify the reviewing HREC of your inability to continue as Coordinating Principal Investigator.
- Notify the reviewing HREC of the failure to commence the study within 12 months of the HREC approval date or if a decision is taken to end the study at any of the sites prior to the expected date of completion.
- Notify the reviewing HREC of any matters which may impact the conduct of the project.
- If your project involves radiation, you are legally obliged to conduct your research in accordance with the Australian Radiation Protection and Nuclear Safety Agency Code of Practice 'Exposure of Humans to Ionizing Radiation for Research Purposes' Radiation Protection series Publication No.8 (May 2005)(ARPANSA Code).
- The HREC, authorising institution and/or their delegate/s may conduct an audit of the project at any time.

Yours sincerely

[redacted]

Emma Land
Research Ethics and Governance Officer
Research Ethics and Governance
The Royal Children's Hospital Melbourne
Phone : (03) 9345 5044
Email : rch.ethics@rch.org.au
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From: **Astrid Nordmann** anordmann@swin.edu.au
Subject: SHR Project 2016/202 - Ethics clearance (Expedited approval based on RCH HREC approval ref: 36128A)
Date: 8 August 2016 at 1:03 pm
To: Christopher McCarthy cdmccarthy@swin.edu.au
Cc: RES Ethics resethics@swin.edu.au

To: Dr Chris McCarthy, FSET

Dear Dr McCarthy,

SHR Project 2016/202 – Developing a socially assistive humanoid robot as a therapeutic aid for paediatric rehabilitation
Dr Chris McCarthy, FSET
Approved Duration: 09-08-2016 to 31-12-2018
(RCH HREC ref.: 36128A)

I refer to your application submitted for Swinburne ethics clearance for the above project.

Relevant documentation pertaining to the application, as emailed on 02 August 2016 with attachments, and subsequent email correspondence sent on 04 August 2016, was given expedited ethical review on behalf of Swinburne's Human Research Ethics Committee (SUHREC) by a delegate significantly on the basis of the ethical review conducted by the Royal Children’s Hospital Human Research Ethics Committee (RCH ref: 36128A)

I am pleased to advise that, as submitted to date and as regards Swinburne, ethics clearance has been given for the above project to proceed in line with standard on-going ethics clearance conditions outlined below and as follows. The RCH HREC may need to be apprised of the Swinburne ethics clearance.

- All human research activity undertaken under Swinburne auspices must conform to Swinburne and external regulatory standards, including the *National Statement on Ethical Conduct in Human Research* and with respect to secure data use, retention and disposal.

- The named Swinburne Chief Investigator/Supervisor remains responsible for any personnel appointed to or associated with the project being made aware of ethics clearance conditions, including research and consent procedures or instruments approved. Any change in chief investigator/supervisor requires timely notification and SUHREC endorsement.

- The above project has been approved as submitted for ethical review by or on behalf of SUHREC. Amendments to approved procedures or instruments ordinarily require prior ethical appraisal/clearance. SUHREC must be notified immediately or as soon as possible thereafter of (a) any serious or unexpected adverse effects on participants and any redress measures; (b) proposed changes in protocols; and (c) unforeseen events which might affect continued ethical acceptability of the project.

- At a minimum, an annual report on the progress of the project is required as well as at the conclusion (or abandonment) of the project. Information on project monitoring, self-audits and progress reports can be found on the Research Intranet pages. (However, formats required by or submissions to the RCH HREC in this regard may be acceptable all things being equal.)

- A duly authorised external or internal audit of the project may be undertaken at any time.

Please contact the Research Ethics Office if you have any queries about on-going ethics clearance as regards Swinburne, citing the Swinburne project number. Please retain a copy of this email as part of project record-keeping.

Yours sincerely,
Astrid Nordmann

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Appendix C

Questionnaires and Evaluation Methods

This appendix includes the questionnaires and the evaluation methods used during the different studies.

The questionnaires used to gather data from the participants during the evaluation of the prototype are the following:

Physiotherapist Questionnaire, page 283.

Guardian/Parent Questionnaire-A: Observing a session being delivered by a physiotherapist with the robot, page 287.

Guardian/Parent Questionnaire-B: Parents delivering a rehabilitation session with the robot, without a physiotherapist in the participants room, page 291.

Patient Questionnaire, page 295.

We have designed an Objective Structured Assessment form for the last study of the thesis to evaluate a therapy session delivered by a parent. Also a Self Report questionnaire to be filled in by parents after each rehabilitation session:

Objective Structured Assessment when Delivering Therapy with the NAO robot, page 299.

Self-Report after delivering therapy with the NAO robot, page 305.

Physiotherapist Questionnaire

In order to improve the performance and your experience with Nao (the robot), we would like you to fill in this anonymouse questionnaire. Please, if you have any questions, feel free to ask the researchers.

1st Part

Please rate the following statements using the following scale:
Strongly disagree — Disagree — Neutral — Agree — Strongly agree

1.1. **I would be afraid to make mistakes using the robot:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.2. **I find the robot scary:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.3. **I think it's a good idea to use the robot:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.4. **I have everything I need to make good use of the robot:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.5. **If I have access to the robot, I think I'll use it in the next therapy sessions:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.6. **I think the robot can be adaptive to what I need:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.7. **I think I will know quickly how to use the robot:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.8. **I think the robot is useful to help in paediatric therapy:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.9. **I think the staff would like me using the robot:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.10. **I would trust the robot if it gave me advice:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.11. **I would be afraid to break something when using the robot:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.12. **I find the robot intimidating:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.13. **The robot would make therapy sessions more interesting:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.14. **I know enough of the robot to make good use of it:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.15. **If I have access to the robot, I am certain to use it in the next therapy sessions:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.16. **I think the robot will only do what I need at that particular moment:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.17. **I find the robot easy to use:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.18. **It would be convenient to have the robot for therapy sessions with kids:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.19. **I think parents would like me using the robot:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.20. **I would follow the advice the robot gives me:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.21. **If I have access to the robot, I'm planning to use it during the next therapy sessions:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.22. I think the robot will help me when I consider it to be necessary:
Strongly disagree ○—○—○—○—○ Strongly agree

1.23. I think I will be able to use the robot without any help if I have been trained:
Strongly disagree ○—○—○—○—○ Strongly agree

1.24. I think the robot can help me with many things during paediatric sessions:
Strongly disagree ○—○—○—○—○ Strongly agree

1.25. I think patients would like me using the robot:
Strongly disagree ○—○—○—○—○ Strongly agree

1.26. I think I will be able to use the robot when there is someone around to help me:
Strongly disagree ○—○—○—○—○ Strongly agree

1.27. I think it would give a good impression if I should use the robot:
Strongly disagree ○—○—○—○—○ Strongly agree

1.28. I think I will be able to use the robot when I have a good manual:
Strongly disagree ○—○—○—○—○ Strongly agree

2nd Part

Please rate your impression of the robot on these scales:

2.1. Fake ○—○—○—○—○ Natural
2.2. Dead ○—○—○—○—○ Alive
2.3. Dislike ○—○—○—○—○ Like
2.4. Incompetent ○—○—○—○—○ Competent
2.5. Machinelike ○—○—○—○—○ Humanlike
2.6. Stagnant ○—○—○—○—○ Lively
2.7. Unfriendly ○—○—○—○—○ Friendly
2.8. Ignorant ○—○—○—○—○ Knowledgeable
2.9. Unconscious ○—○—○—○—○ Conscious
2.10. Mechanical ○—○—○—○—○ Organic
2.11. Unkind ○—○—○—○—○ Kind
2.12. Irresponsible ○—○—○—○—○ Responsible
2.13. Artificial ○—○—○—○—○ Lifelike
2.14. Unpleasant ○—○—○—○—○ Pleasant
2.15. Unintelligent ○—○—○—○—○ Intelligent
2.16. Moving rigidly ○—○—○—○—○ Moving elegantly
2.17. Inert ○—○—○—○—○ Interactive
2.18. Awful ○—○—○—○—○ Nice
2.19. Foolish ○—○—○—○—○ Sensible
2.20. Apathetic ○—○—○—○—○ Responsive

Please rate your emotional state on these scales during the session with the robot:

2.21. Anxious ○—○—○—○—○ Relaxed
2.22. Pessimistic ○—○—○—○—○ Optimistic
2.23. Agitated ○—○—○—○—○ Calm
2.24. Tired ○—○—○—○—○ Energetic
2.25. Quiescent ○—○—○—○—○ Surprised

3^{rd} Part - Five Open Questions

3.1. What do you think is missing in the robot to be a useful legitimate aid tool?

3.2. Which role (demonstrator/motivator/companion/coach/other) of the robot has attracted you most and/or least. Why?

3.3. Which is the most important feature that should be fixed/implemented as soon as possible in the robot?

3.4. How would you rate this child in this session?

3.5. Is there anything else that you would like to say about the robot or the session?

RESEARCHERS USE ONLY:

4. **Date**: ________________
5. **Code**: ________________
6. **Notes:**

Parent/Guardian Questionnaire - A

In order to improve the performance and your experience with Nao (the robot), we would like you to fill in this anonymouse questionnaire. Please, if you have any questions, feel free to ask the researchers.

About you

00. **How old are you?** I am ________ years old.

1st Part

Please rate the following statements using the following scale:
Strongly disagree — Disagree — Neutral — Agree — Strongly agree

1.1. **I would be afraid to make mistakes using the robot:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.2. **I find the robot scary:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.3. **I have everything I need to make good use of the robot:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.4. **I think it's a good idea to use the robot:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.5. **I think I will know quickly how to use the robot:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.6. **I think the robot is useful for paediatric rehabilitation:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.7. **I would trust the robot if it gave me advice:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.8. **I would be afraid to break something when using the robot:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.9. **I find the robot intimidating:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.10. **I know enough of the robot to make good use of it:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.11. **The robot would make my kid's therapy sessions more interesting:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.12. **I find the robot easy to use:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.13. **It would be convenient to have the robot for therapy sessions together with the physiotherapist:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.14. **I would follow the advice the robot gives me:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.15. **I think I can use the robot without any help:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.16. **It would be convenient to have the robot for therapy sessions when the physiotherapist is not in the session:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.17. **I think I can use the robot when there is someone around to help me:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.18. **I think the robot can help my child with many things**
Strongly disagree ○—○—○—○—○ Strongly agree

1.19. I think I will be able to use the robot when I have a good manual:
Strongly disagree ○—○—○—○—○ Strongly agree

2nd Part

Please rate your impression of the robot on these scales:

2.1. Fake ○—○—○—○—○ Natural
2.2. Dead ○—○—○—○—○ Alive
2.3. Dislike ○—○—○—○—○ Like
2.4. Incompetent ○—○—○—○—○ Competent
2.5. Machinelike ○—○—○—○—○ Humanlike
2.6. Stagnant ○—○—○—○—○ Lively
2.7. Unfriendly ○—○—○—○—○ Friendly
2.8. Ignorant ○—○—○—○—○ Knowledgeable
2.9. Unconscious ○—○—○—○—○ Conscious
2.10. Mechanical ○—○—○—○—○ Organic
2.11. Unkind ○—○—○—○—○ Kind
2.12. Irresponsible ○—○—○—○—○ Responsible
2.13. Artificial ○—○—○—○—○ Lifelike
2.14. Unpleasant ○—○—○—○—○ Pleasant
2.15. Unintelligent ○—○—○—○—○ Intelligent
2.16. Moving rigidly ○—○—○—○—○ Moving elegantly
2.17. Inert ○—○—○—○—○ Interactive
2.18. Awful ○—○—○—○—○ Nice
2.19. Foolish ○—○—○—○—○ Sensible
2.20. Apathetic ○—○—○—○—○ Responsive

Please rate your emotional state on these scales during the session with the robot:

2.21. Anxious ○—○—○—○—○ Relaxed
2.22. Pessimistic ○—○—○—○—○ Optimistic
2.23. Agitated ○—○—○—○—○ Calm
2.24. Tired ○—○—○—○—○ Energetic
2.25. Quiescent ○—○—○—○—○ Surprised

3rd Part - Five Open Questions

3.1. Do you think the robot was useful for this rehabilitation session? Why?

3.2. Given the opportunity and some training, would you be prepared to use the robot without a physiotherapist present?

3.3. What things about the robot could be added, changed or fixed to make the robot more useful to you and your child's rehabilitation?

3.4. What things about the robot don't you like? Why?

3.5. Is there anything else that you would like to say about the robot or the session?

RESEARCHERS USE ONLY:

4. **Date**: ________________
5. **Code**: ________________
6. **Notes:**

Parent/Guardian Questionnaire - B

In order to improve the performance and your experience with Nao (the robot), we would like you to fill in this anonymouse questionnaire. Please, if you have any questions, feel free to ask the researchers.

About you

00. **How old are you?** I am ________ years old.

1st Part

Please rate the following statements using the following scale:
Strongly disagree — Disagree — Neutral — Agree — Strongly agree

1.1. **I would be afraid to make mistakes using the robot:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.2. **I find the robot scary:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.3. **I have everything I need to make good use of the robot:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.4. **I think it's a good idea to use the robot:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.5. **I think I will know quickly how to use the robot:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.6. **I think the robot is useful for paediatric rehabilitation:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.7. **I would trust the robot if it gave me advice:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.8. **I would be afraid to break something when using the robot:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.9. **I find the robot intimidating:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.10. **I know enough of the robot to make good use of it:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.11. **The robot would make my kid's therapy sessions more interesting:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.12. **I find the robot easy to use:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.13. **It would be convenient to have the robot for therapy sessions together with the physiotherapist:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.14. **I would follow the advice the robot gives me:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.15. **I think I can use the robot without any help:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.16. **It would be convenient to have the robot for therapy sessions when the physiotherapist is not in the session:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.17. **I think I can use the robot when there is someone around to help me:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.18. **I think the robot can help my child with many things**
Strongly disagree ○—○—○—○—○ Strongly agree

1.19. I think I will be able to use the robot when I have a good manual:
Strongly disagree ○—○—○—○—○ Strongly agree

2nd Part

Please rate your impression of the robot on these scales:

2.1. Fake ○—○—○—○—○ Natural
2.2. Dead ○—○—○—○—○ Alive
2.3. Dislike ○—○—○—○—○ Like
2.4. Incompetent ○—○—○—○—○ Competent
2.5. Machinelike ○—○—○—○—○ Humanlike
2.6. Stagnant ○—○—○—○—○ Lively
2.7. Unfriendly ○—○—○—○—○ Friendly
2.8. Ignorant ○—○—○—○—○ Knowledgeable
2.9. Unconscious ○—○—○—○—○ Conscious
2.10. Mechanical ○—○—○—○—○ Organic
2.11. Unkind ○—○—○—○—○ Kind
2.12. Irresponsible ○—○—○—○—○ Responsible
2.13. Artificial ○—○—○—○—○ Lifelike
2.14. Unpleasant ○—○—○—○—○ Pleasant
2.15. Unintelligent ○—○—○—○—○ Intelligent
2.16. Moving rigidly ○—○—○—○—○ Moving elegantly
2.17. Inert ○—○—○—○—○ Interactive
2.18. Awful ○—○—○—○—○ Nice
2.19. Foolish ○—○—○—○—○ Sensible
2.20. Apathetic ○—○—○—○—○ Responsive

Please rate your emotional state on these scales during the session with the robot:

2.21. Anxious ○—○—○—○—○ Relaxed
2.22. Pessimistic ○—○—○—○—○ Optimistic
2.23. Agitated ○—○—○—○—○ Calm
2.24. Tired ○—○—○—○—○ Energetic
2.25. Quiescent ○—○—○—○—○ Surprised

3rd Part - Five Open Questions

3.1. How confident did you feel about operating the robot when a therapist was not present?

○ Completely confident.
○ Somewhat confident.
○ Somewhat unconfident.
○ No confidence at all.

Why did you feel this way?

3.2. To what extent did you feel the attention you needed to give the robot impacted on the level of attention/assistance you could give to your child?

○ No impact.

○ Minor impact.

○ Moderate impact.

○ Significant impact.

Can you provide any reasons for your response?

3.3. To use the robot independently what training would you need? What things about the robot could be added, changed or fixed?

3.4. Did operating the robot improve your trust in the system? Why?

3.5. In what ways (if any) do you believe the robot assists your child whilst in hospital or a therapy session?

RESEARCHERS USE ONLY:

4. **Date**: __________________
5. **Code**: __________________
6. **Notes:**

Patient Questionnaire

In order to improve the performance and your experience with Nao (the robot), we would like you to fill in this anonymouse questionnaire. Please, if you have any questions, feel free to ask the researchers.

1st Part

Please rate the following statements using the following scale:
Strongly disagree — Disagree — Neutral — Agree — Strongly agree

1.1. **I find the robot scary:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.2. **I think it's a good idea to use the robot:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.3. **I enjoy the robot talking to me:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.4. **I consider the robot is friendly:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.5. **I think the robot should keep coming to my sessions:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.6. **When talking with the robot I felt like I'm talking to a real person:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.7. **I would trust the robot if it gave me advice**
Strongly disagree ○—○—○—○—○ Strongly agree

1.8. **I find the robot intimidating:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.9. **The robot would make my exercises more interesting:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.10. **I enjoy doing things with the robot:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.11. **I feel the robot understands me**
Strongly disagree ○—○—○—○—○ Strongly agree

1.12. **I think the robot will help me if he comes to my exercise sessions:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.13. **It sometimes felt as if the robot was really looking at me:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.14. **I would trust the robot more than the physiotherapist if he told me what to do:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.15. **It's good to make use of the robot:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.16. **The robot is fun:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.17. **I think the robot is nice:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.18. **I think the robot can help me with many things:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.19. **I can imagine the robot to be a living creature:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.20. **I would trust the robot more than my parents if he told me what to do:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.21. **I find the robot boring:**
Strongly disagree ○—○—○—○—○ Strongly agree

1.22. I often think the robot is not a real person:
Strongly disagree ○—○—○—○—○ Strongly agree

1.23. I would follow the advice the robot gives me:
Strongly disagree ○—○—○—○—○ Strongly agree

1.24. Sometimes the robot seems to have real feelings:
Strongly disagree ○—○—○—○—○ Strongly agree

2nd Part

Please rate your impression of the robot on these scales:

2.1. Fake ○—○—○—○—○ Natural
2.2. Dead ○—○—○—○—○ Alive
2.3. Dislike ○—○—○—○—○ Like
2.4. Incompetent ○—○—○—○—○ Competent
2.5. Machinelike ○—○—○—○—○ Humanlike
2.6. Stagnant ○—○—○—○—○ Lively
2.7. Unfriendly ○—○—○—○—○ Friendly
2.8. Ignorant ○—○—○—○—○ Knowledgeable
2.9. Unconscious ○—○—○—○—○ Conscious
2.10. Mechanical ○—○—○—○—○ Organic
2.11. Unkind ○—○—○—○—○ Kind
2.12. Irresponsible ○—○—○—○—○ Responsible
2.13. Artificial ○—○—○—○—○ Lifelike
2.14. Unpleasant ○—○—○—○—○ Pleasant
2.15. Unintelligent ○—○—○—○—○ Intelligent
2.16. Moving rigidly ○—○—○—○—○ Moving elegantly
2.17. Inert ○—○—○—○—○ Interactive
2.18. Awful ○—○—○—○—○ Nice
2.19. Foolish ○—○—○—○—○ Sensible
2.20. Apathetic ○—○—○—○—○ Responsive

Please rate your emotional state on these scales during the session with the robot:

2.21. Anxious ○—○—○—○—○ Relaxed
2.22. Pessimistic ○—○—○—○—○ Optimistic
2.23. Agitated ○—○—○—○—○ Calm
2.24. Tired ○—○—○—○—○ Energetic
2.25. Quiescent ○—○—○—○—○ Surprised

3rd Part - Five Open Questions

3.1. Would you like to do another session with the robot? Why?

3.2. What is the thing you like the most about the robot? Why?

3.3. Is there anything that you don't like about the robot?

3.4. What extra things would you like the robot to do?

3.5. Is there anything else that you would like to say about the robot or the session?

RESEARCHERS USE ONLY:

4. **Date**: ________________
5. **Code**: ________________
6. **Notes:**

Delivering Therapy with the NAO Robot

Basic Information about the session

Code: ________________ **Date:** ______________________ **Time:** ______________

Patient: __________________ **Facilitator:** __________________ **Observer:** __________________

Other people in the room: ____

Ex.1: ______________________________ **Ex.2:** ______________________________

Ex.3: ______________________________ **Ex.4:** ______________________________

Ex.5: ______________________________ **Ex.6:** ______________________________

Initiation of the Session

1. **Before starting the session, at participants arrival or when getting ready for the session.**

   Parent's attitude. Tick the option(s) that apply.

   ○ Positive attitude
   ○ Positive attitude, using the robot as a motivator
   ○ Positive attitude, including some sort of bribery/rewards to motivate the patient
   ○ Important part of the recovery
   ○ Chore
   ○ Other (please explain):

   How is the session framed?

   ○ Like a game
   ○ Important part of the recovery
   ○ Chore
   ○ Other (please explain):

Demonstration

2. **Before starting each exercise the robot does a demonstration. Tick the option(s) that apply for each exercise**

	Parent	Ex.1	Ex.2	Ex.3	Ex.4	Ex.5	Ex.6
2.1	The parent uses the robot demonstration to explain the exercise to the patient	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
2.2	The parent reminds the patient the exercise to do	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
2.3	The parent gets distracted and misses the demonstration, but knows how to continue	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
2.4	The parent gets distracted, the robot is flashing and doesn't know what to do next	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
2.5	The parent ignores the robot	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
2.6	Other						

	Patient	**Ex.1**	**Ex.2**	**Ex.3**	**Ex.4**	**Ex.5**	**Ex.6**
2.7	The patient pays attention to the robot demonstration	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
2.8	The patient reminds the parent the exercise to do	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
2.9	The patient gets distracted and misses the demonstration, but knows how to continue	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
2.10	The patient gets distracted, the robot is flashing and doesn't know what to do next	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
2.11	The patient ignores the robot	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
2.12	Other						

During the Exercise

Parent

3. **When doing the exercises, tick the option(s) that apply for each exercise about the parent**

	Parent						
	Parent - Involved	**Ex.1**	**Ex.2**	**Ex.3**	**Ex.4**	**Ex.5**	**Ex.6**
3.1	The parent is observing and helping assisting robot/child	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
3.2	The parent is observing closer to the patient	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
3.3	The parent is observing from a distance	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
3.4	The patent is distracted with other things (phone, talking, etc.)	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
3.5	The parent is not paying attention to the patient	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
3.6	Other						
	Parent - Prompts	**Ex.1**	**Ex.2**	**Ex.3**	**Ex.4**	**Ex.5**	**Ex.6**
3.7	The parent corrects posture/technique (hands on patient)	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
3.8	The parent uses prompts from the robot to correct their child technique	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
3.9	The parent provides verbal and visual prompts / indications (eg. touch my hand)	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
3.10	The parent provides encouraging statements	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
3.11	The parent uses prompts from the robot to encourage their child	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
3.12	The parent provides only verbal prompts / indications	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
3.13	No prompts	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
3.14	Other						

	Parent - Moderation	**Ex.1**	**Ex.2**	**Ex.3**	**Ex.4**	**Ex.5**	**Ex.6**
3.15	The parents gives the patient that satisfaction of completion of the task	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
3.16	The parent makes the exercise harder/easier (progression/regression)	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
3.17	The parent lets the child to not finish the exercises due to exhaustion/losing technique	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
3.18	The parent provides/mentions rewards/bribery to engage the child	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
3.19	The parent asks the child to beat the robot (competition style)	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
3.20	Other						

Patient

4. **When doing the exercises, tick the option(s) that apply for each exercise about the patient**

	Patient						
	Patient-Facilitator Interaction	**Ex.1**	**Ex.2**	**Ex.3**	**Ex.4**	**Ex.5**	**Ex.6**
4.1	The patient follows the instructions of the facilitator	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
4.2	The patient and the facilitator talk during the session	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
4.3	The patient asks the facilitator to be quiet because they want to listen to the robot	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
4.4	The patient asks the facilitator to be quiet	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
4.5	The patient argues with the facilitator	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
4.6	The patient gets angry to the facilitator	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
4.7	Other						
	Patient - Feedback	**Ex.1**	**Ex.2**	**Ex.3**	**Ex.4**	**Ex.5**	**Ex.6**
4.8	The patient finds and mentions the exercise easy	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
4.9	The patient finds and mentions the exercise hard	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
4.10	The patient complains about the exercise (Pain, etc.)	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
4.11	The patient dislikes the exercise (Negative comments)	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
4.12	The patient is just not interested in the exercise	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
4.13	The patient complains about the instructions/cues provided by the robot	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
4.14	The patient complains about the instructions/cues provided by the facilitator	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
4.15	Other						

	Patient-Robot Interaction	**Ex.1**	**Ex.2**	**Ex.3**	**Ex.4**	**Ex.5**	**Ex.6**
4.16	The patient is willing to interact with the robot verbal communication	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
4.17	The patient is willing to interact with the robot helping/assisting	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
4.18	The patient is willing to interact with the robot tapping its head	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
4.19	The patient follows the robot instructions	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
4.20	The patient follows the robot instructions	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
4.21	The patient looks at the robot	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
4.22	The patient ignores the robot	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
4.23	The patient dislikes the robot (negative comments or facial expressions)	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
4.24	The patient dislikes the robot and yells at it	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
4.25	The patient dislikes the robot and the session has to be aborted	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
4.26	Other						

Distractions

5. **When doing the exercises, tick the option(s) that apply for each exercise about the patient**

	Distractions						
	Distractions affecting the patient	**Ex.1**	**Ex.2**	**Ex.3**	**Ex.4**	**Ex.5**	**Ex.6**
5.1	No distractions	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
5.2	TV	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
5.3	Phone/iPad	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
5.4	People (busy room, etc.)	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
5.5	Disengagement	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
5.6	Other						

Completion of the Exercise

6. **Using the following options, rate the level of completion of the exercise.**

Options:
1 - The patient refuses to do or try to do the exercise
2 - The patient refuses to finish the exercise (eg. A whole set)
3 - The patient does the exercise with a very bad performance or with lack of interest
4 - The patient easily gets distracted and/or misses some repetitions
5 - The patient does all the sets of exercises

Tick the corresponding circle 1 - 2 - 3 - 4 - 5

Exercise 1: 1 ○—○—○—○—○ 5
Exercise 2: 1 ○—○—○—○—○ 5
Exercise 3: 1 ○—○—○—○—○ 5
Exercise 4: 1 ○—○—○—○—○ 5
Exercise 5: 1 ○—○—○—○—○ 5
Exercise 6: 1 ○—○—○—○—○ 5

7. Reasons for not completing the exercise (tick if required)

	Reasons	**Ex.1**	**Ex.2**	**Ex.3**	**Ex.4**	**Ex.5**	**Ex.6**
7.1	Exhaustion						
7.2	Pain						
7.3	Behaviour						
7.4	Distractions						
7.5	Disengaged						
7.6	Other (indicate):						

Self-Report After Using the NAO Robot

Basic Information about the session

Code: ____________ **Date:** ________________ **Time:** ____________

Patient: ______________________ **Parent/Facilitator:** ______________________

Other people in the room: ____

Exercise 1: ________________________ **Exercise 2:** ________________________

Exercise 3: ________________________ **Exercise 4:** ________________________

Exercise 5: ________________________ **Exercise 6:** ________________________

Patient (as reported by Parent/Facilitator)

1. **Read the text in the box to the patient in order to ask them how they were feeling when doing the exercises. Circle all the faces that apply, and briefly explain why underneath. Number the faces in order that they apply (eg. 1 the most relevant, 3 the least relevant).**

> *"How did you feel when doing the exercises? These faces show different emotions that you might have felt when doing exercises. This face is very sad [Point Very Sad face], this one is happy, and this one is very happy [Point Excited Face]. Were you afraid of the robot [Point Afraid face]? Do you think the robot is boring [Point Boring face]? Or maybe the robot confused you [Point Confused face]? Were your sleepy [Point Sleepy face]? Or the robot made you angry [Point Angry face]?"*


Very Sad


Sad


Neutral


Happy


Excited


Afraid


Bored


Confused


Sleepy


Angry

Parent/Facilitator

Robot

2. Did you use the robot during the rehabilitation session?

○ Yes, without any problems
○ Yes, but the robot fell at the end
○ Not really, the robot fell at the beginning of the session
○ Not really, we tilted the robot and then it stopped working
○ Not really, the robot run out of battery
○ No, the robot was talking but not moving
○ No, the robot didn't work
○ No, we didn't know how to use it
○ No, we preferred to do the exercises without the robot
○ No, the robot was not present/available
○ Other (please explain)

Patient's mood during the session

3. Please describe the patient's mood when doing the exercises, by selecting one or more of the options below. Number your choices in ascending order, eg. "1" applied the most.

Patient's mood	No.
Very Sad	
Sad	
Neutral	
Happy	
Very Happy	
Afraid	
Bored	
Confused	
Very bored / Disengaged	
Angry	
Frustrated	
Other (indicate):	

Completion of the Exercise

4. Using the following options, rate the level of completion of the exercise.
Options:
1 - The patient refuses to do or try to do the exercise
2 - The patient refuses to finish the exercise (eg. A whole set)
3 - The patient does the exercise partly or with lack of interest
4 - The patient easily gets distracted and/or misses some repetitions
5 - The patient does all the sets of exercises

Tick the corresponding circle 1 - 2 - 3 - 4 - 5

Exercise 1:	1 ○—○—○—○—○ 5
Exercise 2:	1 ○—○—○—○—○ 5
Exercise 3:	1 ○—○—○—○—○ 5
Exercise 4:	1 ○—○—○—○—○ 5
Exercise 5:	1 ○—○—○—○—○ 5
Exercise 6:	1 ○—○—○—○—○ 5

5. **Reasons for not completing the exercise (tick if required)**

Reasons	**Ex.1**	**Ex.2**	**Ex.3**	**Ex.4**	**Ex.5**	**Ex.6**
Exhaustion						
Pain						
Behaviour						
Distractions						
Disengaged						
Other (indicate):						

6. **Thank you for completing this survey. If you have any other comments, please write below using the free space. Once you finish, fold this document along the dashed line, and return it to the physiotherapist, or keep it with the robot.**

Once completed, fold the document along the dashed line.
Please return to **Jo Butchart** at the **Victorian Paediatric Rehabilitation Service**
The Royal Children's Hospital Melbourne
and
Swinburne University of Technology

Once completed, fold the document along the dashed line.
Please return to **Jo Butchart** at the **Victorian Paediatric Rehabilitation Service**
The Royal Children's Hospital Melbourne
and
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