Abstract

Youth with cerebral palsy (CP) have limitations in physical abilities that make it difficult for them to participate in traditional physical activity and social interaction. Exergames, video games combined with physical activity, represent a promising approach to allow youth with CP to participate in physical activity while socializing with others. However, commercial exergames present challenges to accessibility that can be difficult to overcome for youth with CP. One way of addressing these problems is by designing exergames considering the physical abilities and limitations of this population, providing methods and interfaces to interact with the game that are easy for them to use.

This research provides insights into how to design exergames that youth with CP can play, enjoy, and use effectively to socially communicate and interact with peers. To approach this challenge, a year-long participatory iterative design process was followed, involving medical professionals, game designers, computer scientists, kinesiologists, physical therapists, and youth with CP. The result of this process was a set of guidelines for the design of gameplay that is accessible for youth with CP, a set of guidelines to provide social accessibility in online games for youth with CP and an online exergame implementing these guidelines. The game was evaluated over two home-based studies with youth with CP. The first study focused on the evaluation of the playability of the game over eight weeks. The second study focused on the evaluation of the game’s effectiveness as a platform for social interaction for youth with CP over ten weeks. Results from both studies show that the games built following the guidelines were indeed playable, enjoyable and effective at allowing and promoting social interaction.
Co-Authorship

I hereby declare that this thesis incorporates material that has been published in the following two papers:


The research published in both publications was conducted under the supervision of Professor Nicholas Graham, director of the EQUIS Lab at Queen’s University. I, the candidate, was the lead author in both publications. These publications benefit from the contributions of my supervisor and the following coauthors:

Affiliation: Holland Bloorview Kids Rehabilitation Hospital

- Dr. Darcy Fehlings, Physician Director, specializing in youth with CP. Head of the CP Discovery Lab. Dr. Fehlings provided guidance during the design and testing phases of the games described in both publications. She facilitated access to a group of youth with CP who attended the hospital for medical treatment and facilitated space at the hospital where we could conduct design sessions part of this research. Dr. Fehlings conducted with us these design sessions and the home-based evaluations described in each publication. She contributed editing both publications suggesting proper terminology and descriptions of the characteristics of youth with CP.

- Dr. Virginia Wright, physiotherapist, expert in youth with CP. She provided expert guidance on the capabilities of youth with CP, the design of exergaming hardware specialized for youth with
CP and longitudinal study design. Dr. Wright contributed ideas of how to report the results of the home-based study described in the second publication.

- Lauren Switzer, Research Project Manager at Dr. Fehlings lab. She managed the logistics related with recruiting youth with CP for our design sessions and home-based studies; facilitating a space at the hospital for our design and preparation sessions before the home-based studies; and providing participants of the studies technical assistance by replacing faulty equipment.

Affiliation: EQUIS Lab at Queen’s University

- Zi Ye, full time programmer and artist. He was the lead designer and developer of the exergame described in both publications. Mr. Ye implemented game ideas that came out of in lab discussions and game ideas of his own giving the games the look and sound of his style.

- Mallory Ketcheson and Adrian Schneider, both MSc students at the School of Computing. They contributed organizing and filtering data collected during the home-based study described in the second publication. They also helped writing and editing the manuscript submitted for publication.

- Chad Richards, PhD student at the School of Computing, and Shelly Bursick, postdoctoral fellow helped managing the logistics of conducting the home-based study described in the second publication. Mr. Richards, in addition, helped proofread the manuscript before publication.

My participation in both publications include contributions to all phases of the development of the exergame described and evaluated in both publications, including eliciting requirements through the design sessions at the hospital; contributing to the design of exergames with game ideas and additional requirements for research through the games; evaluating design alternatives through pilots at the lab, design sessions and home-based trials; analyzing collected data, and reporting findings. In particular, I took the lead on the analysis of how to provide action-oriented games for youth with CP, focus of the first publication, and on the evaluation of the social aspects of the game, focus of the second publication.
Acknowledgements

I would like express my deepest thanks to my supervisor Dr. Nicholas Graham for his years of support and guidance. I am privileged to have worked with him during the course of this research. He has been an excellent mentor and a source of inspiration. Thank you for your optimism, patience, and friendship.

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Finally, I am forever grateful for the love and unwavering support of my parents Elvia Maria and Luis Enrique. Without them none of this would have been possible.
Statement of Originality

I hereby certify that all of the work described within this thesis is the original work of the author. Any published (or unpublished) ideas and/or techniques from the work of others are fully acknowledged in accordance with the standard referencing practices.

Hamilton Andres Hernandez Alvarado

January, 2015
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<td>CP</td>
<td>Cerebral Palsy</td>
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<tr>
<td>DDA</td>
<td>Dynamic Difficulty Adjustment</td>
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<td>DDR</td>
<td>Dance Dance Revolution</td>
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<td>EA</td>
<td>Electronic Arts</td>
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<td>GMFCS</td>
<td>Gross Motor Function Classification Scale</td>
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<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
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<tr>
<td>HBKRH</td>
<td>Holland Bloorview Kids Rehabilitation Hospital</td>
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<tr>
<td>HR</td>
<td>Heart Rate</td>
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<tr>
<td>HRMI</td>
<td>Heart Rate Monitor Interface</td>
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<tr>
<td>MACS</td>
<td>Manual Ability Classification Scale</td>
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<td>MS</td>
<td>Multiple Sclerosis</td>
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<td>PACES</td>
<td>Physical Activity Enjoyment Scale</td>
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Chapter 1

Introduction

Youth with motor limitations such as those associated with cerebral palsy (CP) have decreased opportunities to participate in traditional exercise such as playing baseball, going for a bike ride, or kicking a ball with their friends. A resulting lack of exercise can contribute to a cycle of deconditioning as youth with CP grow into adulthood, resulting in deteriorating physical function [11,45], which might also negatively impact their opportunities for social interaction [55]. In fact, youth with CP have been reported to have fewer social experiences with peers than youth without disabilities, in part due to special needs in transportation, accessible facilities, and coordination of assistive services [55].

Exergames, video games combined with physical activity, represent a promising way of enabling youth with CP to perform the exercise they need to break this cycle of deconditioning while allowing them to socialize with others in a fun way from the comfort of their homes. But designing exergames that youth with CP can play and use effectively to socialize with others can be challenging. First, limitations in physical abilities of youth with CP make it difficult for them to play many existing exergames; and second, there are challenges to social play such as establishing player groups and playing with players with different abilities that need special consideration.

The goal of this research is to provide insights into how to design exergames that youth with CP can play, enjoy, and use effectively to socially communicate and interact with peers. We accomplish this goal through four contributions: first, a comprehensive set of guidelines for the design of exergames that youth with CP can play and enjoy; second, a set of game examples that illustrate the implementation of these guidelines; third, a set of guidelines for social accessibility
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in exergames for youth with CP; and finally, a set of examples that illustrate the implementation of the design guidelines for social accessibility.

1.1 Problem

The problem addressed in this research is that: *limitations in physical abilities associated with CP make it difficult for youth with CP to play and enjoy moderately vigorous exergames and effectively use them for socially communicating and interacting with others.*

In Canada and the United States, 2 to 3 out of 1,000 children have CP [56, 67]. We see an opportunity for moderately vigorous exergames in youth with CP who are able to walk independently, which represent sixty-eight percent of the youth with CP [56]. Specifically, we target youth with CP who require a mobility aid such as a walker or a manual wheelchair to walk (those classified at the level III of the Gross Motor Function Classification Scale (GMFCS) [86]) (see Figure 1-1). Henceforth, “youth with CP” refers to youth with CP at GMFCS level III, unless otherwise specified.

![Figure 1-1: Children with CP have limitations that prevent them from playing traditional exergames.](image)

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Youth with CP have significant limitations in their abilities that make it difficult for them to play traditional exergames (see Figure 1-1). Restricted gross motor function makes it difficult or impossible to perform many forms of physical exercise such as dancing or running. Players must devote significant attention to performance of accurate gross-motor movements, reducing attention available for actual gameplay. Limitations in their manual ability make it difficult for them to aim precisely and rapidly, or to manipulate numerous controls concurrently on traditional game controllers. Deficits in visual-motor coordination make it difficult to time actions (such as hitting a baseball with a bat), and deficits in visual-spatial skills make it difficult to construct a mental map of the game world.

In addition, networked games can introduce unintended barriers to group play that can be difficult to deal with for people with CP. Grouping with other players in a virtual world might require traveling over large virtual geographies with complex visual cues, which might take time and be difficult for people with seriously affected visual-spatial processing abilities. Additionally, players might need to use cluttered graphical user interfaces to access gestures and commands necessary to start or carry out social interactions with others. These tasks require manipulating small objects such as buttons on a game controller or a keyboard, presenting difficulties for people with limited manual ability. Finally, differences in players’ abilities might affect the way people with CP interact with others during social play. For example, for people with different physical abilities, it can be difficult to stay together with others online as they move around the virtual world, or to effectively react to time-sensitive game events during online competitions or cooperative group battles.

1.2 Motivation

This research is motivated by the effectiveness of exergames in enabling people with motor difficulties to perform moderately vigorous physical activity [50,117], the potential of multiplayer exergames to provide engaging gaming experiences that might lead to long term adherence to
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exercise [48,89], and the opportunities that networked games offer for social interactions among
people with disabilities [39,51,73,107]. Several studies have shown that it is possible to develop
and use exergames to motivate exertion and improve fitness in people with motor disabilities
[46,50,117], and sometimes even bring other benefits such as improved balance [4,18] and
improved performance in upper and lower extremities [23,83,95,117] for people with CP
[25,46,94], and people with other physical disabilities, such as stroke, Parkinson disease, spinal
cord dysfunction and multiple sclerosis (MS) [18,81,117,120]. But not every exergaming
intervention has been successful. For example, Graves et al., studying people without disabilities,
found that the energy used when playing Wii Sports games was not high enough to contribute
toward the recommended daily amount of exercise in adolescents [43], and home-based
interventions with the Wii have suffered from a sharp decline in interest over periods of 12 weeks
or more [85,94]. These issues call for the design of novel exergames that can motivate moderate
to vigorous exercise and high adherence over the long term.

Multiplayer exergames attempt to take advantage of the motivational aspects of group activity
[74,78] and can provide additional stimulation compared to single player games [41,48,110,112].
Additionally, networked games have particular promise for people with special needs who are
confined to their homes or care centres. People with physical disabilities have expressed that
online video games offer them the possibility of reaching out to people in situations that would
otherwise be difficult or uncomfortable. This new freedom helps in developing meaningful
relationships and building a community outside the home [39,54]. However, it is not obvious how
to design networked exergames that allow youth with CP to easily and effectively group with
others to start and carry out frictionless social interactions.

One way of addressing these problems in game playability and social play of exergames for
youth with CP is to design exergames considering the physical disabilities associated with CP,
and to provide methods and interfaces for interacting with the game that are easy for them to use.
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Guidelines for the design of games for people with physical disabilities suggest removing interactions with the game that are particularly physically demanding [121], or designing gameplay that does not require precise positioning and aiming or time-sensitive actions, and is tolerant of errors [47]. In terms of designing for social accessibility, there are no recommendations yet on how to address challenges of forming groups with people with motor disabilities. For frictionless group play, an interesting solution is the use of automated balancing techniques that adjust the challenge of the game based on the player’s ability. Some balancing techniques dynamically adjust the difficulty of the game based on the players’ performance [49,98], while others use the players’ physical capabilities as parameters for balancing the game [101].

These approaches seem promising, but little is known about the effectiveness of these strategies for designing exergames that youth with CP can play with others.

1.3 Solution

The solution provided in this thesis is to design exergames for youth with CP based on guidelines for the design of exergames that youth with CP can play and enjoy and guidelines for the design of games that youth with CP can use to socialize with other youth.

Since such guidelines do not exist as of yet, we followed a year-long iterative and incremental participatory design process involving medical professionals, game designers, computer scientists, kinesiologists, physical therapists, and youth with CP and focused on the abilities and limitations of youth with CP to come up with a solution appropriate for this population and possibly useful for others. Throughout this process we developed a new set of guidelines for providing gameplay accessibility for youth with CP and a new set of guidelines for providing social accessibility in online games for youth with CP.
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1.3.1 Hypotheses

There are two main hypotheses to our solution of gameplay accessibility and social accessibility.

1. By using our new game design guidelines for gameplay accessibility, it is possible to design exergames that youth with CP can play and enjoy.

2. By following our new design guidelines for social accessibility, we can allow youth with CP to socially interact with other youth through video games.

1.4 Steps in the solution

The major parts of our solution include the identification and evaluation of a set of guidelines for gameplay accessibility for youth with CP and a set of guidelines for the design of games that allow youth with CP to socialize with others. These steps performed are:

1. Formalize and define a set of guidelines for the design of exergames that provide both accessibility, and fun and engaging gameplay for youth with CP. These guidelines are discussed in detail in chapter 3.

2. Formalize and define a set of guidelines for the design of video games that provide social accessibility for youth with CP. These guidelines are discussed in detail in chapter 5.

3. Design an exergame that allows the evaluation of both the design guidelines for gameplay accessibility and the design guidelines for social accessibility. We created the exergame Liberi, and we illustrate how to use the design guidelines for gameplay accessibility by providing a specific set of examples which we describe in detail in chapter 3. The specific strategies implemented to comply with the design guidelines for social accessibility are described in detail in chapter 5.

4. Evaluate the effectiveness of the design guidelines for gameplay accessibility with youth with CP. We evaluated Liberi in terms of playability and enjoyment during an eight-week study in which five youth with CP played the game from home. We describe the design and results of this study in chapter 4.
Chapter 1: Introduction

5. Evaluate the effectiveness of the design guidelines for social accessibility in games for youth with CP. We evaluated Liberi as a means of fostering social interaction in youth with CP through a study where ten participants played the game from home for ten weeks. We describe the design and results of this study in chapter 6.

1.5 Contributions

This thesis considers the physical limitations of youth with CP that prevent them from playing exergames with other youth and presents four main contributions to the area of human computer interaction, specifically in the design of exergames, which are intended to allow youth with CP to play and enjoy exergames with other youth. The contributions are:

1. **A novel set of guidelines for the design of exergames for youth with CP that support accessible, fun and engaging gameplay.**

2. **A set of examples that illustrate how to implement these guidelines** and that have been integrated and tested in an exergame that youth with CP can play and enjoy.

3. **A novel set of design guidelines for providing social accessibility in games for youth with CP.**

4. **A set of examples illustrating the implementation of the design guidelines for social accessibility** that we have integrated and tested in an online exergame that youth with CP can use to effectively socialize.

This research was conducted in the context of a broader project exploring the health and social benefits of exergaming for youth with CP, and benefits from collaboration with a multi-disciplinary research group including, in addition to my supervisor:

- Dr. Darcy Fehlings, Physician Director at Holland Bloorview Kids Rehabilitation Hospital (HBKRH), pediatrician, specializing in youth with CP. Dr. Fehlings contributed to the planning and execution of our design sessions, providing guidance about the design and evaluation of our exergaming station and exergame in terms of its therapeutic
relevance. Dr. Fehlings facilitated access to the space at the hospital where we conducted our design sessions. She also facilitated access to a group of youth with CP who attended the hospital for medical treatment and to clinical personnel who assisted us during our design sessions.

- Dr. Virginia Wright, physiotherapist at HBKRH, who provided expert guidance on the capabilities of youth with CP, the design of exergaming hardware specialized for youth with CP and the design of a home-based study with our game, described in chapter 6.

- Bill Johnson from Ideas for Independent Living Inc., mechanical engineer, who helped us design and build an exergaming station specialized for youth with CP. Mr. Johnson attended the design sessions where the station was tested with youth with CP.

- Zi Ye, full time programmer and artist, lead designer and developer of the Liberi exergame. Mr. Ye was in charge of implementing the game, considering requirements and game ideas identified during our group meetings and design sessions at the hospital, providing and implementing ideas of his own about the style of the games and gameplay, and attending the design sessions where the usability and enjoyment of the game were evaluated.

- Dr. Ryan Rhodes, professor in exercise psychology at the University of Victoria, and Dr. Darren Warburton, professor in kinesiology at the University of British Columbia, provided offline guidance for determining necessary exercise levels of exercise that could lead to health benefits for youth with CP.

- Ian Jarvis, professional game producer at Electronic Arts, provided offline feedback about the game style and usability.

In my role in this research group, I contributed to all phases of the development of our solution, including the planning of focus groups; facilitating data collection tools such as custom questionnaires and interviews scripts for eliciting accessibility and enjoyment requirements
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through our participatory design process; identifying additional requirements to allow collection of research data through the game; contributing to the design of the game with game ideas and alternatives to address accessibility, enjoyment requirements; evaluating design alternatives through pilots at the lab, design sessions at the hospital and home-based trials; analyzing collected data, and reporting findings to the group. From a logistics point of view, I worked closely with Zi Ye at our lab, to guarantee that the game addressed the identified requirements; and worked together with Dr. Fehlings’ group to plan, set up and execute our participatory design sessions and home-based evaluations with youth with CP. In particular, I took the lead on the analysis of how to provide action-oriented gameplay for youth with CP (focus of chapter 3) and on the evaluation of the social aspects of a networked exergame for youth with motor disabilities (discussed in chapter 5).

1.6 Thesis outline

The rest of this thesis is organized as follows. Chapter 2 discusses the literature motivating this research, elaborating the problem, and surveying current approaches. This chapter presents a detailed definition of: cerebral palsy (CP), covering its characteristics, and problems and needs of people with CP; opportunities in exergames and social gaming for youth with CP and other physical disabilities; barriers and challenges of existing exergames and social games for youth with CP; and existing approaches to overcome some of these barriers. Chapter 3 presents our work towards the specification of the guidelines for the design of accessible gameplay for youth with CP, including the method followed, the resulting guidelines, and the description of the game Liberi where we made use of the guidelines. Chapter 4 describes an eight-week home-based trial where the playability and enjoyment of Liberi were evaluated, including the design of the study and the results obtained. Chapter 5 focuses on the guidelines for social accessibility in games for youth with CP. This chapter includes the design guidelines we followed to allow social interaction in Liberi, and a detailed set of examples that illustrate the use of these design
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guidelines. Chapter 6 describes the design and results of a second ten-week home-based
evaluation of the game as a social platform for youth with CP. Chapter 7 provides an overall
discussion of this thesis’ contributions, including reflections on our design process, assumptions,
limitations, threats to validity, remaining challenges and potential future work on the design of
accessible video games that youth with CP can play with others.
Chapter 2

Literature Review

This chapter reviews the literature motivating this research and elaborating the problem: *limitations in physical abilities associated with CP make it difficult for youth with CP to play and enjoy moderately vigorous exergames and effectively use them for socially communicating and interacting with other youth.* First, we present a detailed definition of cerebral palsy (CP), its characteristics and why it is difficult for people with CP to engage in traditional forms of exercise and social interaction. Second, I focus on exergames as a promising alternative to traditional exercise, reviewing different exergaming platforms, commercial exergames, and exergames that have come out of the research community, discussing how they are or are not suitable for youth with CP. Next, I review research studying the benefits and barriers in exergames, followed by a review of exergames as a form of rehabilitation. Then I present the challenge of engagement and long term adherence to exercise and rehabilitation and how it has been traditionally addressed. I dedicate a section to multiplayer exergaming as a promising approach for motivating engagement and adherence and as a promising social platform for people with disabilities. I then discuss the challenges associated with designing exergames for youth with CP and barriers to social play for youth with CP. Finally, approaches to tackling these challenges are explained with a section on design for gameplay accessibility and a section on design for social accessibility.

2.1 Cerebral palsy

Cerebral palsy (CP) is a group of disorders affecting the development of movement and posture, causing activity limitations. In Canada, 2 to 3 out of every 1,000 children have CP [67]. CP is attributed to disturbances in the development of the fetal or infant brain [91], and it can affect gross motor skills and fine motor skills.
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According to the Gross Motor Function Classification Scale (GMFCS) [86], CP can affect physical function to different degrees. People at GMFCS level I can perform daily life activities such as transportation with light limitations, whereas people at GMFCS level V need physical assistance and powered mobility. People at GMFCS level III require a mobility aid like a walker for most activities, and a self-propelled or powered wheelchair for moving long distances. Figure 2-1 shows a child with GMFCS level III CP.

An analysis of the prevalence and classification of CP in the U.S. found that 38.1% of children with CP were at GMFCS level I, 16.4% were at GMFCS level II, 13.2% at GMFCS level III, 15.1% at GMFCS level IV and 17.1% at GMFCS level V. Youths with CP who can move independently without a mobility aid or with the aid of a walker or a wheelchair (those classified at the GMFCS levels I to III [86], 68% of the total population with CP) have higher chances to participate in moderately vigorous exercise when specialized equipment is provided than those requiring physical assistance (those at the GMFCS levels IV and V) [46]. Henceforth, this review focuses on the special needs of youth with GMFCS level III CP.

![Figure 2-1: Person with GMFCS level III CP and person with MACS level II CP.](image)

Left: child with GMFCS level III CP using a mobility aid. Right: teenager with MACS level II CP using an Xbox game controller.
Similarly to the Gross Motor Function Classification Scale, the Manual Ability Classification System (MACS) [29] has been used to describe the degree of limitations in manual abilities for people with CP. Youth at MACS level I can handle objects independently and successfully with minor limitations in the ease of performing tasks requiring speed and accuracy. Youth at MACS level V cannot handle objects and have severely limited ability to perform even simple actions, requiring total assistance for performing daily life activities.

Eliasson et al. [29] reported a high correlation between the GMFCS and MACS. According to this correlation, the majority (54%) of youth classified at the level III of the GMFCS are classified at the levels I (18%) and II (36%) of the MACS. Youth at MACS level II perform almost the same activities as youth in level I, but the quality of the performance is decreased or the performance is slower. Figure 2-1 depicts the hands of a teenager with CP classified in MACS level II operating an Xbox game controller.

Due to these limitations in physical function, youth with GMFCS level III and MACS level II CP cannot engage in casual exercise such as playing baseball, going for a bike ride or kicking a ball with friends. This lack of exercise can contribute to a cycle of deconditioning as they grow into adulthood, resulting in deteriorating physical function [11,45], which might also negatively impact their opportunities for social interaction [55]. Youth with CP have been reported to have fewer social experiences with peers than youth without disabilities, in part due to special needs in transportation, accessible facilities, and coordination of assistive services [55].

2.2 Exergames
Exergames can be defined as “video games that require physical activity in order to play” [17]. Exergames represent a promising alternative for youth with CP to get the exercise they need, potentially contributing to breaking their cycle of deconditioning. This section reviews representative exergaming platforms, commercial exergames and academic exergames introduced
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over the years, showing how they allow the players to interact with the games using movements of the body, and how some of these are or are not suitable for youth with CP.

2.2.1 Exergaming platforms and exergames

Multiple commercial exergaming platforms allow players to interact with video games by performing actions that involve movements of the body.

Foot operated pads: Some of the earliest examples of exergaming platforms include foot operated pads like the Amiga Joyboard, where a traditional joystick is replaced by a balance board on which players stand and lean to specify direction [96], and the Nintendo Power Pad, where players press buttons on a mat using their feet [96] (see Figure 2-2). One of the most successful foot-operated platforms is Konami’s Dance Dance Revolution (DDR), where players dance on a touch-sensitive pad to the rhythm of music and on-screen visual cues [68]. A more recent popular foot-operated pad is the Nintendo Wii Balance Board [87], where players stand and lean (changing their center of gravity) to provide input to exergames.

Ergometers: Other exergaming platforms use more traditional exercise equipment such as stationary bikes to interface with video games. Early examples were Nameco’s Prop Cycle and

![Figure 2-2: Foot operated pads.](image)

From left to right: Nintendo Power Pad, arcade style Dance Dance Revolution, and Nintendo Wii Balance Board.
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![Ergometers]

**Figure 2-3: Ergometers.**

From left to right: Namco's Downhill bikers, the PC Gamer Bike mini, a Cateye GameBike.

Downhill Bikers which required players to pedal on stationary bikes to control their on-screen avatars [84] (see Figure 2-3). More recently, the Cat Eye Gamebike [33] and the Motion Fitness Exerbike replaced gamepad controls for the Sony Play Station 2 [111]. On these bikes, pedaling is used for speed control in racing games such as the Need for Speed series, and the handlebars are turned left and right to steer the on-screen vehicle. Similarly, the 3D Innovations PCGamerBike Mini is a pedaling unit used to interact with computer games [32] (see Figure 2-3). This bike, combined with a game controller, can be used to steer and move players in first-person shooter or role-playing games.

**Motion detection peripherals:** More recently, peripherals have been released for commercial game consoles allowing forms of gaming that require body movement. Nintendo introduced the Wii Remote Plus [80], a wireless hand-held controller that includes an accelerometer and a gyroscope, allowing the players to interact with video games through arm gestures (see Figure 2-4). Similarly, Sony released the Play Station Move [99], a motion-controller that captures players’ upper-body movement using an accelerometer, a magnetometer, a rate sensor, and computer-vision, while Microsoft offers the Kinect sensor for the Xbox 360 and Xbox One [69], a vision based system that allows the players to interact with games using their whole body. All these peripherals are depicted in Figure 2-4.
Commercial exergames: A common game genre for all these platforms and movement peripherals is sports simulation games. A popular example that uses the Wii Remote Plus is Nintendo Wii Sports, including games such as Tennis, Boxing, Bowling, Golf and Baseball. In these games, the player performs gestures mimicking real-world actions of a particular sport. For example, in Wii Tennis, the player makes forehand and backhand swings with the Wii Remote Plus to control a virtual racquet and hit tennis balls on the screen. Similar games exist for other consoles and peripherals such as Sports Champions for the PlayStation Move, and Kinect Sports for the Microsoft Kinect.

Other popular genres for these platforms are virtual training and dancing games. EA Sports Active includes a virtual personal trainer that leads players through warm-up, cool down and exercise routines. EA Sports Active is available for Nintendo Wii, PlayStation 3 and Xbox 360. In the Nintendo Wii version, players use the Nintendo Wii Remote to perform upper body movements and use the Wii Nunchuck peripheral [80] attached to one leg to track lower body movements. EA Sports Active 2 adds a heart rate monitor arm-strap to track the intensity of the player’s workout, letting players know whether they are under- or over-exerting, and a motion sensor for the leg, making tracking of the lower body more accurate. The PlayStation 3 version of EA Sports Active 2 also features a motion sensor to strap in one arm. Figure 2-5 shows two youth playing tennis in EA Sports Active 2 for the Nintendo Wii. Nintendo Wii Fit [87] is a video game
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Figure 2-5: Virtual training and dancing games.


featuring activities such as yoga, strength training, aerobics and balance games featuring the Nintendo Balance Board (shown in Figure 2-2). Successful dancing games include the Just Dance series available for Nintendo Wii and Xbox 360 (see Figure 2-5), and Dance Central 3 for Xbox 360. In these games players follow choreographies of modern songs and can also keep track of burned calories as they dance [82,118].

**Academic exergames:** Several platforms and exergames have also come out of research labs. Ahn et al. [3] provided an alternative to traditional treadmill running with their exergame Swan Boat. In this game, players control a virtual boat on a screen by running on a treadmill and performing arm gestures while wearing movement sensors on their arms (Figure 2-6).

Gao and Mandryk [34] developed GrabApple, an exergame to allow casual exergaming. In GrabApple people move their whole body in front of a Kinect to control a virtual hand on the screen trying to grab as many falling apples as possible and avoiding falling bombs (Figure 2-7).

Another example of a computer-vision exergame is QuiQui's Giant Bounce [44], a video game for children that senses the player's body movements and voice using a webcam and a microphone. In this game, players control a character using their whole body according to a fast-moving story, for example by flexing their body to the sides and flapping their arms.
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Whitehead et al. [115] created Posemania (Figure 2-8), an academic dance simulation game that encourages players to use their whole body to perform precise moves to the rhythm of the music. This game uses accelerometers worn on the players’ upper and lower limbs to keep track of precise movements of the entire body, unlike DDR, which focuses only on foot placement.

Stepmania\(^1\) is a rhythm game similar to DDR, where players use a foot-operated pad similar to the one in DDR (dance pad) to play. Stepmania is available as an open source free game that can

\(^1\) http://stepmania.com
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be used as an extensible rhythm game engine capable of supporting a variety of rhythm-based
game types. Baradoy [6] made use of Stepmania’s source code and introduced the player's heart
rate as part of the game controls, giving birth to DanceBeat. DanceBeat attempts to keep the
player's heart rate within a specified submaximal range by increasing or decreasing the physical
demands of the game. Dance Beat requires a computer, a dance pad, and a heart rate monitor to
play.

Another open source game made an exergame is Neverball2. Neverball is a navigation game
where players collect coins in a limited period of time. Berkovsky et al. [15] turned Neverball
into an exergame by awarding players extra time in return of on-the-spot jumps. The player’s
jumps are detected with an accelerometer configured specifically to detect this type of movement
(see Figure 2-9).

Mueller et al. [74,76] have combined traditional exercise equipment and motion detection
technologies to create exergames that players located in different regions can play together. In
Breakout for Two [74] (Figure 2-10), each player kicks a soccer ball toward a projection wall
trying to break a set of virtual bricks shared by both players. In this game, a camera is used to

Figure 2-9: The exergame Neverball.

A player wears a motion sensor in the back that detects jumping gestures [15].

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2 http://neverball.org/
track the soccer ball instead of the player. The goal in Table Tennis for Three [76] is similar, but now each of the three players uses a table tennis racquet to hit a ball towards the wall shared by all the players. In this game, sound sensors in the back of the wall are used to detect what area of the wall the ball hits, but the player’s movement is not directly tracked.

2.2.2 Exergaming equipment and youth with CP

We have just reviewed exergaming platforms that allow players to interact with exergames in different ways. But not all of these platforms allow moderately vigorous exercise in youth with CP.

Youth with CP have muscle weakness, reduced range of motion, and poor control over their movements. These aspects of their disability pose difficulties with most existing exergaming infrastructures: many youth with CP who use mobility aids have challenges with the finely controlled movement required by Kinect or Wii titles; they cannot balance on a Wii balance board, jump or flex their bodies to the sides on a timely manner, accurately step on the controls of a foot operated pad, or sit on an upright GameBike. A few studies have been reported where people with CP play commercial Wii titles [25,48,50] or custom built games using Nintendo Wii peripherals [40], but in these cases, players were in higher levels of mobility (GMFCS level I and
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II) [48,50], or they were playing with goals different to reaching moderate or vigorous levels of exercise [25,40].

A successful exergaming platform for youth with CP needs to address their physical challenges to enable exercise that is sufficiently vigorous to lead to health benefits. While these challenges must be solved for any exergaming station, they are exacerbated when designing for youth with motor disabilities, and failure to solve them represents a significant barrier to adoption of such a system.

Prior to our work, there was no equipment specifically allowing youth with CP to play moderately-vigorous exergames.

2.3 Research on exergames

Research on exergames has focused on studying how effectively exergames produce health benefits when compared to traditional exercise. Positive results have shown that exergames can increase enjoyment of physical activity when compared to traditional exercise for people without motor disabilities [41,88,89,111,113] and people with motor disabilities [25,117]. Some exergames have been found to effectively support physical activity in the moderate to vigorous rate [46,111,117], and to lead to improvements in physical fitness [89,111,117] and body composition in overweight or obese children [64,65,103,104]. Also, exergames have helped to overcome traditional barriers to exercising in a group: with networked exergames, people do not have to be in the same location to be able to play together [74,76,78], and people with significantly different fitness levels can exercise together [112].

However, there are challenges for exergames that require further research. Exergames have been found to suffer from a decline in enjoyment and subsequent use over the long term [9,85,88,94], and not every exergame motivates high levels of energy expenditure that might produce health benefits [7,43,85].
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Studies that have found positive results in the use of exergaming suggest several characteristics that make exergames useful. Some of these characteristics are:

- **Low cost**: commercial platforms such as the Nintendo Wii, Xbox Kinect, PlayStation Move, and the GameBike are relatively inexpensive, ranging from $100 USD to $600 USD, making it practical to adopt them for use in the home. There are also low-cost virtual reality exergaming platforms for rehabilitation of people with motor disabilities built using webcams and common objects [21,23,120].

- **Active**: in traditional video games, players play while sitting down; exergames, in the other hand, require upper-body movements, lower-body movements or both, producing higher levels of energy expenditure. Several researchers report that independent of the level of energy expenditure achievable with exergames, their active nature helps reduce sedentary behavior, offering potential health benefits to a wide range of individuals [16,31,65,66,106,113].

- **Vigorous**: several exergames have been found to be effective in motivating high levels of energy expenditure at the moderate to vigorous level. DDR [122], Wii titles such as Wii boxing [50], and cycling-based exergames [46,89,111,117] have been particularly successful. All these games have in common that they are fast-paced.

- **Immersive**: exergames can distract the attention of the player from the strain of exercise toward the interaction with the game. Warburton et al. [89,111] found that exercising on a GameBike was more engaging and enjoyable than cycling while listening to music. Similarly, Mark and Rhodes [66] found significantly higher enjoyment and use over six weeks when children were provided with a GameBike compared to using a bike in front of a TV. Both studies suggest that exercise combined with an interactive activity such as gaming is more engaging and enjoyable than exercising with a passive activity like listening to music or watching TV. Similarly, Stach and Graham [102] found that haptic
feedback in exergames increases players’ sense of presence in game environments, increasing immersion and improving enjoyment in the game. An example of haptic feedback in cycling-based exergames is changing the pedal resistance to match the terrain type.

- **Group exercise friendly:** group activity can have a positive influence on exercise motivation and adherence [5,14,112]. Several commercial and academic exergames allow players to play with others side by side or over the network taking advantage of the motivational benefits of exercising together. Network technologies and balancing mechanisms in exergames allow interactions between players that are otherwise not possible in traditional exercise. Mueller et al. [74,76,78] have proposed several exergames where players who are in different regions can play together. Stach [112] and Mueller [77] introduced heart rate based techniques that allow people with different fitness levels to exercise together having an enjoyable experience. In Frozen Treasure Hunter [119], two players can play together choosing different roles that require different types of physical activity, allowing players with different exercise preferences to still play together (see Figure 2-11). Section 2.6 presents an extended review of multiplayer exergaming, including benefits and challenges.

![Figure 2-11: The Frozen Treasure Hunter exergame.](image)

Left: game screen. Right: player and controls [119].
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Even though several benefits have been reported of the use of exergames, there has been criticism about their use as a viable option for physical activity and health benefits [7,43,85,94,113], suggesting that special considerations must be taken into account for their effective use. Some of the challenges for exergames are:

- **Spontaneity:** Baranowsky et al. [7] reported that exergames do not spontaneously motivate 9- to 12-year-olds youth to engage in physical activity. In a 12-week study, they gave a Nintendo Wii with two new exergames to a group of youth, while another group received a Nintendo Wii with two popular sedentary video games. They found no differences in the amount of physical activity of both groups. Owens et al. [85] found similar results in a 12-week study with children and adults who received the Nintendo game Wii Fit without an exercise prescription. Both studies argue that there is no health value in simply having exergames available for people to play, and they suggest that explicit instructions to use exergames are necessary.

- **Exercise Intensity:** There has been criticism focusing on the relatively light intensity requirements of many exergames where minimal bodily movement is enough for success [85,113]. As an example, Graves et al. [43], studying people without disabilities, found that the energy used when playing Wii Tennis, Wii Boxing and Wii Bowling was less than in the authentic sports and was not high enough to contribute toward the recommended daily amount of exercise in adolescents. In defense of cases like this, Warburton [113] argues that just the observed increase of overall physical activity levels in youth and the opportunity for promoting healthy lifestyle behaviours might be already meaningful for changing sedentary behaviours, which might lead to health improvements.

- **Declining adherence:** Another challenge in exergames is the reported decline of enjoyment and adherence over the long term [9,85,88,94]. One reason observed by Rhodes et al. is that exergaming equipment (a GameBike in their case) might be found
uncomfortable and choppy [88]. As mentioned in Section 2.2.2, this factor is particularly important when designing exergaming equipment for people with motor disabilities. Another explanation for this decline is that exergames, equally to traditional video games, suffer from declining interest and subsequent use as the novelty of the games wears off [59]. One alternative is to continually release novel exergames to reengage the consumers’ interest, as the current video game industry does. Although this seems like an effective solution, its cost is usually too high [8].

The following section reviews the use of exergames for rehabilitation purposes, showing additional benefits attributed to the use of exergaming and how challenges presented in this section still need special attention.

2.4 Exergames as a form of rehabilitation

One additional benefit of exergames is their use as an alternative to physical therapy. Exergames have proven to make physical activity more accessible, pleasurable, and engaging for people with motor limitations [19,22,46,50,72,117]. They can be played from home, removing logistical difficulties of going to a specialized rehabilitation centre, and can also be played with others over a network, providing social contact with peers [47]. Exergames have been successfully used for rehabilitation of people with motor disabilities. Custom-designed games [23,83,95] and commercial games [25,94] have been used to help improve upper extremity impairment and balance in youth with CP, improve oxygen uptake and maximum work capability in youth with spinal cord dysfunction [117], and improve balance in patients with stroke [4,18,40].

Most exergames used for rehabilitation fall into two categories: 1) slow games for rehabilitation of upper extremities and balance; and 2) fast-paced/metabolically-demanding games for improving cardiovascular and body fitness.
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2.4.1 Slow-paced rehabilitation exergames

Slow-paced rehabilitation exergames require and track slow, smooth and accurate movements of the upper and/or lower body. In general, these games require players (patients) to step or extend their arms to reach for physical or virtual objects [23,40,120], perform gestures with their hands extending their fingers [21], stand and maintain balance on a Wii balance board [4,106], and/or to adopt and maintain specific positions with their entire body [116]. Tanaka et al. [105] wrote a review of leading consumer exergaming systems that can be used for this purpose. In their review, they give detailed specifications of the Nintendo Wii Remote, Nintendo Wii Balance Board, Sony Play Station Move and Microsoft Xbox 360 Kinect, discussing advantages and disadvantages for researchers interested in using them.

There are several examples of research work for this therapeutic purpose. Geurts et al. [40] designed a set of games they denote as “Slow Fun”, focused on extending range of motion and balance for people with CP. In these games, they use the Wii balance Board, Wii Remote, webcams and markers to track the players’ movements (see Figure 2-12).

Anderson et al. [4] developed the “Virtual Wiihab” system (Figure 2-13), including four rehabilitation-centric games, aiming to increase trunk control, lower extremity stability, and patient’s balance. In their system, players interact with the game by leaning on a Wii Balance

Figure 2-12: The Slow Fun rehabilitation games.

Left: the Catching Dishes game using a webcam and markers. Right: the Flying Dragons game using the Nintendo Wii balance board.
Board and using a Wii Remote. Chen et al. [23] studied the use of a Play Station EyeToy and a tracker-based virtual reality system for rehabilitation of upper extremities in youth with CP. They found that in four weeks their intervention helped improve the youth’s reaching behaviors, making them faster, smoother and/or straighter.

Burke et al. [20] developed three camera-based games for stroke rehabilitation. In their games players use markers in one or both hands depending on the game, and perform slow but timely reaching movements with their arms following visual clues in the screen, such as a rabbit peering out of a hole (Figure 2-14).

Yu et al. [120] designed an interactive multimedia system for rehabilitation of patients with Parkinson disease (Figure 2-15). In order to make it feasible, the system was designed under several restrictions, e.g. the system should be usable in clinical space, repetitive, variable, engaging, immersive and adaptable.

2.4.2 Fast-paced/metabolically demanding exergames
We define fast-paced/metabolically demanding exergames as those requiring continuous and moderate-to-vigorous exercise that produces high levels of energy expenditure. These games aim for cardiovascular improvements helping to maintain or improve body fitness. Exergames that
lead to significant metabolic requirements and health benefits in this area usually involve exercises with the whole body (jumping, crouching, ducking) [70,113], frenetically dancing at a certain rhythm [122], performing quick swinging and punching gestures [50], or vigorously pedaling bicycles with the hands or the legs [46,47,101,117]. Examples of this type of game include Kinect Adventures [70], where players run, jump, duck and dodge their way through obstacle courses; DDR, where players frenetically dance hitting buttons on a pad at the rhythm of the music [122]; and Wii boxing, where players try to punch the opponent and dodge their attacks [48,50].

Such fast-paced exercises can be difficult for people with physical limitations, which limits the number of exergames suitable for this type of therapy in this population. Studying commercial exergames, Hurkmans et al. [50] found that Wii Sports Tennis and Boxing may be useful for increasing activity levels comparable with moderately vigorous exercise and promote healthful lifestyles in people with CP; however, his studies included people with CP at the higher levels of gross motor function (GMFCS I and II). Cycling-based approaches have been found to be feasible and effective for motivating moderate-to-vigorous exercise in youth with motor disabilities. Widman et al. [117] used the GameCycle (Figure 2-16) for including aerobic training in rehabilitation of patients with spinal cord dysfunction, finding that this system “seems to be
adequate” as an exercise device to improve oxygen uptake and maximum work capability for this population.

Both types of rehabilitation exergames face the challenges described in Section 2.3. In the case of slow-paced rehabilitation, adherence is particularly important, since patients need to repeat their exercises over several weeks in order to see improvements in physical function [10,21,52,95]. In the case of rehabilitation for physical fitness, both adherence and exercise intensity are particularly important to improve and maintain body fitness. The American College of Sports Medicine (ACSM) recommends 150 minutes per week of moderate intensity activity (40% of heart rate reserve) for developing and maintaining cardiorespiratory fitness [35,114], but some exergames have lower metabolic requirements, and it is ultimately up to the player to determine the intensity they want to use to play [113]. Furthermore, even though exergaming interventions have reported fitness improvements in people with disabilities from interventions lasting at least six weeks [57,64,103,117], two interventions have been found to suffer a sharp decline of interest over time [85,94].
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The following section describes strategies that have been proposed for the design of exergames that motivate high levels of exertion and long term adherence.

2.5 Motivation and adherence in exergames

Several strategies have been proposed as an attempt to improve motivation towards exercise and to increase adherence. Yim and Graham [119] suggest integrating music, providing short and long term achievable goals, hiding the players’ fitness levels in exergames, facilitating leadership for novice players, removing systemic barriers to grouping, and assisting players in forming groups.

Sinclair et al. [97] introduced the Dual Flow model, a model based on the theory of Flow [24] (the state of total engagement in an activity) adapted to exergaming. They suggest that exergames should offer a balance between challenge and skill in order to be attractive, and also between the intensity required by the game and the player’s fitness in order to be effective.

In the case of exergames for rehabilitation purposes, Burke et al. [19] present several requirements to ensure high engagement. They suggest creating and maintaining meaningful play by providing appropriate feedback to the patients’ actions, handling failure carefully to ensure players do not lose motivation due to failing to accomplish the game tasks, and making sure that games present an ideal level of challenge for each individual player. Notelaers et al. [81] also propose a set of requirements for the design of engaging and motivational rehabilitation games for patients with multiple sclerosis. They suggest that the difficulty must be adapted to the different patients, the games must be challenging, progress must be rewarded, and that all patients must be able to make progress. Similarly, Smedinck et al. [98], working with patients with Parkinson’s disease, recommend offering an adequate level of challenge to maintain high motivation.
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Many of these motivational factors have been applied to existing commercial and research exergames. However, one of the most motivational elements in video games and exercise widely studied in existing literature is the opportunity for social interaction [5,38,39,77,110,119]. The following section is dedicated to this opportunity.

2.6 Multiplayer games

Multiplayer games can enable social interaction in scenarios where it would be otherwise difficult or impossible. Social interactions have been found to improve motivation, enjoyment and long term adherence to exercise [5,52]. However, as we shall see, multiplayer games are not always effective at motivating social interaction [28] and there are challenges in developing multiplayer games for this specific population.

2.6.1 Multiplayer games as an opportunity for social interaction

Multiplayer video games allow connections with other people located at the same place (co-located, see Figure 2-17) or remotely (online, see Figure 2-18) [75,79]. Social interaction around these games can take place in co-located facilities or over a network, bringing physically separated people together [75].

Multiplayer video games engage 76% of typically developing youth [53] representing an
important part of their overall social experience. Networked/online games have particular promise for young people with disabilities whose leisure activities occur primarily in the home with parents as play partners [62]. People with physical disabilities have expressed that online video games offer them the possibility of reaching out to people in situations that would otherwise be difficult or uncomfortable. This new freedom helps in developing meaningful relationships and building a community outside the home [54]. Similarly, examples from the literature show that video games represent an innovative leisure activity in long-term care centres for the elderly, providing opportunities for engaging in social interactions and healthy behaviours that might improve the quality of life. In SilverPromenade, for example, elderly people can go on virtual walks through a forest and interact with virtual animals on screen [39]. A six-week study in a long-term care facility found that Nintendo Wii games were more effective for improving affection and self-esteem and reducing loneliness than traditional board games [51]. Also, a pilot study with elders who attend a community activity centre observed that Wii games helped encourage interaction and enhanced social cohesion [107]. Preliminary results from a study using a mobile game specifically designed to foster elders’ social interaction also showed that digital games can indeed motivate fun interactions among players, and provide opportunities to socialize with new people [73].

All these examples are based on co-located play, where the players are in the same room. There has been to date little research on using networked games to increase social interaction in people with motor disabilities.

2.6.2 Multiplayer exergames and their role in motivation to exercise

Group activity has been shown to have a positive effect on motivation and adherence to exercise [5,52]. Multiplayer exergames can take advantage of the motivational aspects of group activity [74,78] and can provide additional stimulation compared to single player games [41,110,112]. Several studies with people without disabilities have proven the effectiveness of multiplayer
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Exergames in increasing enjoyment of exercise. In Swan Boat [3], two players team up in a racing game running on treadmills to have a cooperative exergaming experience. In Jogging over a Distance [79], two joggers can have a social game experience despite running in different regions. Results from both studies agree that social interactions allowed by these games make running more enjoyable than running alone. In Breakout for Two [74], two remotely located players can together play a vigorous game that mixes soccer, tennis and the popular computer game “Breakout”. And in Table Tennis for Three [76], three remotely located players can play a table-tennis-based game. Studies using these games indicate that the social interaction in the games created a feeling of connectedness for the participants, increasing the enjoyment of the activity.

The studies listed above provide evidence for the benefits of multiplayer exergames in exercise enjoyment; however, the contribution of multiplayer exergames to long term adherence remains an open question.

Given that youth with CP usually have decreased access to social activities compared to youth without disabilities, the opportunity to socialize through video games represents a particularly important motivator [55]. Deutsch et al. [25] conducted a study where a child with CP played with a child without CP during one out of eleven sessions, finding that this interaction was not only motivational but also beneficial for the patient whose performance improved after learning the strategies used by his partner to play the game. Similarly, in the case of post-stroke rehabilitation, patients involved in organized group exercise have been found to have significantly higher adherence to home-based exercise [52].

However, social interaction might not always be successful, introducing new challenges that might hinder enjoyment of the game and the physical activity. There are cases where multiplayer conditions might be less appealing than solo conditions, as in the case of people grouped with significantly older or younger peers [14], or disparate fitness levels [78,112], or cases where multiplayer gameplay negatively impacts the therapeutic goals [48].
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Beauchamp et al. [14] found that adults between 30 and 70 years old prefer to exercise alone rather than in group-based settings when their exercise partners are considerably older or younger. This case highlights the importance of choosing the right groups.

Stach [112] studied the challenges of allowing players of different fitness levels to play together in an exergame. In this case some players might find the exercise activity either too challenging or discouraging if their peers have better fitness, or not rewarding/appealing if their peers are less fit. He suggests an effort-based balancing technique based on heart rate, where in-game performance is based on the players’ effort relative to their fitness level.

Studying youth with hemiplegic CP (where only one of the arms is affected), Howcroft et al. [48] found that the opportunity to play with family and friends makes exercise more enjoyable and may translate to more frequent participation in exercise than playing alone. However, in this case, competition urged the players to use their dominant (non-limited) arm more often than in the solo condition, compromising the effectiveness of the multiplayer condition for rehabilitation purposes. In this case, a multiplayer exergame did not meet the therapeutic goal of improving functioning of hemiplegic limbs. This example calls for careful design of multiplayer exergames where interactions motivated in the game do not conflict with the therapeutic purposes.

The previous examples show that multiplayer exergames can be more enjoyable than single player games. But there are significant challenges in the development of multiplayer exergames for youth with CP.

Most existing exergames for people with disabilities are single player [25,40,117], and very few are multiplayer [4,47]. Deutsch et al. [25] report that a child with GMFCS level III CP was able to play Nintendo Wii Bowling with a child without CP during one session, but they used a slow-paced turn-based game where interactions were limited only to sharing strategies and words of encouragement. Howcroft et al. [48] studied multiplayer exergames with youth with CP in the highest range of mobility (GMFCS level I). To date, no one has studied the development of
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multiplayer exergames where youth with GMFCS level III CP engage in moderately vigorous play with other youth. The following section presents the challenges of developing moderately vigorous multiplayer exergames for this population.

2.7 Challenges of developing exergames for youth with CP

Physical disabilities of youth with CP make it challenging to develop moderately vigorous and fun exergames that they can play with others. Limitations in gross motor control [86], manual ability [92], visual-motor integration [91], visual spatial processing [47,91] and motor habituation [37] make it difficult for youth with CP to play exergames with full body motions and control schemes involving several buttons and joysticks. Also, traditional interfaces may make it difficult for youth with CP to start and conduct social interactions with other players.

Motivated by the proven effectiveness of bicycles to support vigorous exercise [111,117], the possibility of making recumbent bikes safe to use for youth with CP [46], and the natural match of pedaling motions to the movement of an avatar in a wide range of game styles, we focus on cycling-based exergames.

Based on the definition and classification of CP [91], the characterization of fast-paced action games that match the pace of moderately vigorous exercise [100], and observation of our target population, the main challenges of playing fast-paced exergames for youth with CP are gross motor control, manual ability, visual-motor integration, visual-spatial processing and motor habituation.

Gross motor control: Compared to youth without disabilities, youth at GMFCS level III have decreased motor control in both legs [86] and are unable to walk without a mobility aid. Spastic diplegic CP is common in this population, where their legs have decreased selective motor control and muscles manifest high levels of stiffness, often causing their legs to pull together, turn inward, and cross at the knees [123]. This makes it difficult to perform traditional exercise such
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as running, jumping or dancing. Cycling-based exercise is possible using a specially-designed recumbent bicycle; however, the CP makes it difficult to pedal smoothly and accurately [46]. We have observed that youth with CP find it difficult to start pedaling a bike when it is completely stopped, to provide a sustained, smooth cadence, and to accurately stop at a target location (e.g., a doorway or ladder in a game).

**Manual Ability:** Fine motor skills are needed for manipulating small objects in a controlled manner, such as pressing buttons or manipulating a joystick on a video game controller. Youth with CP have reduced manual ability [91]; those classified at the MACS level II can handle most objects but with reduced quality and/or speed of achievement [29]. Standard game controllers have been used successfully in studies involving youth with CP [25,46] (see Figure 2-1); however, our participants found it hard to use common control schemes. Specifically, the youth had difficulties pressing different buttons in rapid succession, using multiple buttons at the same time, or selecting a specific button at exactly the right time. All three of these forms of manipulation are required in popular commercial action games (see Figure 2-19). Additionally,

![Controller scheme in a first person shooter game.](http://halo.wikia.com/wiki/Halo_3_Beta)

Figure 2-19: Controller scheme in a first person shooter game.

Source: [http://halo.wikia.com/wiki/Halo_3_Beta](http://halo.wikia.com/wiki/Halo_3_Beta)
networked games offer multiple gestures to start or carry on social interactions through commands assigned to combinations of keys or buttons cluttered in a complex user interface [27], which might present difficulty for people with limitations in manual ability.

**Visual-motor integration:** This ability measures the degree to which people can coordinate visual stimuli and muscular movements. For example, coordination of visual input and motor skills actions is required to aim a tennis racquet at an approaching ball. Youth with CP have lower performance in visual-motor integration tasks than youth without CP. Even though eye responses in youth with CP can be as fast as in youth without CP, hand movements are slower and less efficient [92]. This ability is critical in action games for activities such as aiming, dodging, or jumping onto a moving platform [100].

**Visual-spatial processing:** Over 83% of youth with CP present seriously affected visual-spatial processing abilities [60]. Visual-spatial processing involves the extraction of spatial information from a visual signal. For example, this skill allows people to develop a mental map of an unfamiliar city by walking around. This skill is important in action games where a player might need to quickly determine the best route through a maze or map, to decide quickly whether two points are close enough to be able to jump between them, or to decide how much ahead of a moving target to shoot in order to hit it [100]. In networked games, this limitation can make it difficult to effectively navigate virtual worlds based on complex visual cues or to successfully find places or persons.

**Motor habituation and attention**

During typical development, children habituate motor movement, reducing the attention required to perform common activities such as walking or cycling. Motor habituation is limited in youth with CP [37]. When playing an exergame, they must devote considerable attention to carrying out physical movements such as pedalling. This diverts attention from the gameplay itself, rendering games more difficult to play.
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These limitations in gross motor function, manual ability, visual-motor integration, visual-spatial processing and attention call for cautious design, avoiding the need for time-sensitive operations, complex control scheme, and high attention to gameplay so that youth with CP can play fast-paced exergames.

Differences in players’ abilities

Differences in physical abilities between players present additional challenges for the development of multiplayer exergames for youth with CP. For example, in a cycling-based racing exergame, a player who can pedal faster will win every game, rendering the games boring for one player and frustrating for the other. Also, limitations in manual ability and visual motor integration of youth with CP limit their ability to respond to other player’s attacks in online competitions or their ability to contribute during cooperative group battles, possibly causing the players with better abilities to avoid grouping with players with pronounced limitations. These examples suggest that strategies should be implemented to allow better groupings of players or to decrease the impact of differences in players’ abilities during group play.

Barriers to social play in general networked games

In addition to the challenges imposed by limitations in physical abilities, networked games in general can have unintended barriers to group play that can lead to low social interaction; for example, players of World of Warcraft have been found to spend as little as 25%-30% of their time playing with others [4].

Barriers to interaction in traditional networked games include difficulty in establishing player groups and difficulty supporting play between people with different abilities. For example, players may have difficulty meeting others within a virtual world possibly due to being spread over a large virtual geography, requiring them to travel for a long time before being able to group for a shared activity [28]. Once players have arrived in the same location, they must formally band together as a group, which requires the use of a typically cluttered interface with multiple
options (see Figure 2-20). This, as mentioned before, might be particularly difficult for people with motor disabilities.

Another issue typical in commercial networked games is that players can be hesitant to admit new players to their group. Guilds in World of Warcraft can be highly exclusive, only admitting players at similar levels of experience [28]. One explanation for this exclusivity is that advanced players may see no benefit in cooperating with lower level players [28]. This segmentation of the players and difficulty breaking into existing groups can interfere with social interaction.

**Facing the challenges**

Different strategies have been presented in the literature that could be used to face these challenges. The following section describes strategies to make games playable for people with motor disabilities, and section 2.9 reviews strategies to deal with social barriers in networked games.
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2.8 Design for gameplay accessibility

There has been wide interest in making games that people with motor disabilities can play. As a result, there exist several sets of guidelines for the development of accessible traditional computer games for people with physical and non-physical disabilities. Several of these guidelines have been compiled in the BBC Accessible Games Standard [63], the Game Accessibility Guidelines [30], and the Game Accessibility Recommendations (GARv2-25) [36]. These guidelines are the product of experts in game design and accessibility standards. The guidelines related to the design of games for people with motor disabilities almost uniformly suggest avoiding the need for time-sensitive operations and complex control schemes. The following list summarizes guidelines around the design of the gameplay (challenges, rules and options presented in the game), the game level (virtual space where gameplay takes place), the game mechanics (mechanisms available to the player for playing the game), and the control scheme (physical interface used by the player to control the game), applicable to the design of games for youth with CP:

- **Avoid fast pace** [42]: game elements should move slowly to allow the player time to react.
- **Do not require precise timing** [30,36]: avoid the need to make precise movements at a specific time.
- **Provide a simple control scheme** [30,42,63,121]: reduce to a minimum the number of controls used to play the game, even to only one control.
- **Do not require multiple simultaneous actions** [30,42,63]: avoid mechanics that require holding buttons down or pressing two at the same time.
- **Avoid repeated inputs (button mashing)** [30,63]: do not require rapid consecutive pressing of buttons.

Yuan et al.’s survey [121] analyzes a set of games for people with different disabilities and extracts the techniques used in these games to provide accessibility to players with a specific
disability. Most of their techniques were included in GARV2-25 [36], but there are three additional techniques proposed specifically for players with motor disabilities:

- **Reduction**: remove completely part of the original interaction with the game. An example based on the game Frogger would be removing the possibility for the player to move left or right, allowing only movement up and down.

- **Automation of the player’s input**: reduce the need for detailed control by anticipating the player’s intentions. Examples include steering assistance to avoid obstacles and automatic target lock-on.

- **Scanning of the input**: reduce the number of controls required to manipulate multiple actions by making them accessible through a set of steps which the player can operate with a single button. A scanning system could be a context sensitive action that changes depending on the state of the game, or a multistep scanning mechanism that is the same throughout the game. An example would be using a single button to determine the direction and magnitude of the next swing in a golf game using two steps.

These three strategies can improve game playability by simplifying the player’s input. However, this would not be ideal for exergames, where the goal is to motivate the player to provide moderate-to-vigorous input.

Using all these guidelines might be the right choice for providing accessibility to games, but they tend to produce slow-paced games that do not necessarily motivate moderately vigorous exercise [47]. We can see this in the design of several exergames intended for people with motor disabilities associated with CP [23,40,83], spinal cord dysfunction [117], stroke [20] and multiple sclerosis [81].

Other researchers have identified principles of video game design which are important in the context of rehabilitation in order to make games playable, usable and engaging. From Notelaers et
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al.’s [81] work with patients with multiple sclerosis, we can extract a set of basic requirements to guarantee accessibility, also applicable to the design of exergames for youth with CP:

- The game play must be easy to understand.
- Feedback about users' movements must be clear.
- Patients who have muscle difficulties must be supported by the game.

Finally, an important and general recommendation for the design of exergames for people with motor disabilities is to explore the abilities of the target audience to discover new possibilities and challenges when designing for accessible gameplay [39,46,47].

2.9 Design for social accessibility

Traditional guidelines for the design of accessible gameplay do not necessarily address the issues experienced by youth with CP when trying to engage in social interactions through video games. But some strategies have been used in games for people without disabilities to deal with some of the barriers to social gameplay.

**Strategies in commercial networked games**

Commercial networked games have experimented with strategies to encourage people to group [28]. These include offering different in-game roles for the players to choose from [27,28], steering players towards social gathering points in the virtual world [26], giving players downtime in the game to be social with others [58], allowing players to show off their achievements [13,28], implementing social gestures for avatars [27], and providing matchmaking tools. These solutions may help foster social interactions, but even successful games implementing these solutions have been inconsistent at cultivating group play [28].

For example, even though millions of people have played World of Warcraft, people tend to play alone, especially in early stages of the game, and players tend to think of other players as
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their audience rather than as peers [28]. Ultima Online offered towns with taverns where players could meet and socialize, but these spaces were almost always empty [27].

Game Balancing

One approach to reduce the impact of differences of players’ abilities in performance in the game is the use of game balancing techniques. The goal of balancing techniques is to give a challenging while still enjoyable game experience to players, making the games neither too easy nor too hard.

Balancing techniques can be static configurations that explicitly allow the players to choose a level of difficulty for the game [1] or subtle dynamic adjustments to the difficulty of the game based on the player’s performance, usually known as dynamic difficulty adjustment (DDA) [1,49,93,98].

Examples of both types of balancing can be found in several commercial titles of different game genres. For example, in the popular single player first person shooter Doom, the amount of enemies, their speed and strength can increase or decrease depending on the level of difficulty chosen by the player [1] (see Figure 2-21). And Nintendo’s popular multiplayer racing game Mario Kart allows players to choose a level of difficulty before starting a tournament (see Figure 2-21), and then, during the races, DDA is used to determine the type of items that the players can

Figure 2-21: Levels of difficulty in Doom and Nintendo’s Mario Kart.

Doom (left) and Nintendo's Mario Kart (right) use names for their levels of difficulty, in both cases, arranged from the easiest to the most difficult in top to bottom order.
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use to attack the others based on their position in the race. Usually players left behind get items that help them catch up, whereas players who are in the lead get weak items. This specific type of DDA is usually called “rubber banding”, where the game tries to keep the distance between players short and gives equal opportunities to win to everyone, making the game more challenging for those players ahead and easier for those left behind [93].

Gerling et al. [38] explored the effects of explicit versus hidden balancing techniques in exergames where a person that uses a wheelchair plays with a person without motor limitations. Their techniques were based on balancing techniques used in traditional sports, where based on the players’ abilities, players are given different goals (input type), a different amount of time to reach their goals, and score is counted differently. They found that explicit balancing techniques negatively affect self-esteem of both players and reduce the relatedness between pairs, whereas hidden balancing techniques can improve self-esteem for both players and can balance score differential.

Physical fitness plays an important role in the game performance for people with and without motor disabilities. Physiological information from the players can be used to adjust the difficulty of the game so that people applying similar effort have similar performance in the game, independent of their fitness levels. One approach is the one explored by Stach [112] where the player’s heart rate is used to determine how much effort the player is putting in the game and reward her performance in the game accordingly. Mueller et al. [77] present a similar approach in Running over a Distance, where remotely located joggers are aware of their partner’s exhaustion level through spatial audio cues based on their partner’s breathing and heart rate level. Based on these cues, the players adjust their pace running faster or slower. Their participants described this experience as an engaging cooperative experience not possible in co-located conditions due to different fitness levels.
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Berkovsky et al. [15] present a different use of balancing techniques using DDA in a custom built exergame for people without disabilities. In their game, players are given a certain amount of time to complete a level and are given more time in exchange of jumping in place. In an initial study, they found that players with better gaming skills performed less physical activity to succeed in the game than their peers. A subsequent investigation, showed that dynamic balancing techniques successfully overcame the gaming skills dependence and achieved more balanced activity levels between players with different gaming skills.

Target assistance is another type of technique used for balancing multiplayer games where skills such as targeting are crucial to winning. Bateman et al. [12] studied the effectiveness of three of these techniques (area cursors, target gravity, and sticky targets) in a shooting gallery game finding that assistance significantly reduced score differential, and less skilled players reported having more fun when the techniques helped them be more competitive, while not changing the fun that more skilled players had.

2.10 Summary

In this chapter we reviewed physical limitations associated with CP that make it difficult for youth with CP to play existing fast-paced exergames, and also how the social benefits of online games might not be available for this population. We found promising literature that suggests that custom design around the abilities of people with motor disabilities can provide playability and enjoyment of games; however, little has been done in the context of exergames that serve as a venue for moderately-vigorous exercise and social interaction for youth with CP.

In the following chapter we describe how through a participatory design process we were able to identify a novel set of guidelines that allowed us to develop a fast-paced exergame that youth with CP can play and enjoy. In Chapter 5 we also discuss how we considered the abilities of youth with CP and existing barriers in commercial online games to identify a novel set of design guidelines that allow accessible social interaction among youth with CP through our exergame.
Chapter 3

Design for Gameplay Accessibility

As discussed in the previous chapter, youth with CP can benefit from exercise accessible from the comfort of the home using cost-effective equipment. Traditional approaches to the design and evaluation of exergames with people with motor disabilities focus mostly on targeting slow-paced rehabilitation, and little has been done in terms of aiming for metabolically demanding exercise. Interventions using commercial exergames for the Nintendo Wii, PlayStation Move and Microsoft Kinect report mixed results in terms of their effectiveness for motivating moderately vigorous exercise, suggesting that additional research is still necessary.

Metabolically demanding exergames involve continuous and fast-paced exercise. Examples include dancing frenetically at the rhythm of the music like in advanced modes of Dance Dance Revolution (DDR) [122], jumping, crouching and running in place like in Kinect Adventures [70], running non-stop on a treadmill like in Swan Boat [3], or pedaling a GameCycle [117].

A game genre that matches the fast pace of metabolically demanding exercise is the one of action-oriented games. Action-oriented games challenge the players’ physical skills and coordination [2], usually requiring the player to control an avatar performing a wide range of fast-paced actions such as running, jumping, shooting and racing vehicles. This type of game is also attractive to youth with CP, as we found during a participatory design process.

Youth with CP have limitations in their gross motor skills, manual ability, visual-spatial reasoning, eye-hand coordination and attention, all of which are required for playing action-based games effectively. Developing action-based exergames for youth with CP is challenging, and prior to this work there was little guidance as to how to design them or knowledge of their effectiveness.
Chapter 3: Design for Gameplay Accessibility

The literature has provided recommendations for the development of accessible games for people with motor disabilities such as do not require precise timing [30,36], provide a simple control scheme [30,42,63,121], do not require multiple simultaneous actions [30,42,63], avoid repeated inputs (button mashing) [30,63], automate the player’s input [27], and specifically avoid fast pace [42].

While these guidelines might be useful for producing games that are accessible, and in some cases effective for rehabilitation of the upper body [40] or improving balance in people with motor disabilities, these guidelines produce games that steer away from the fast-pace of action-based gameplay, possibly leading them to be boring.

The following sections of this chapter discuss the characteristics of action-based games and the challenges that youth with CP face when playing them. We review how traditional guidelines for accessibility steer away from action-based gameplay. We then show how through a participatory design process we were able to design action-based minigames that youth with CP can play and enjoy, and how this process led to successful design guidelines. We conclude this chapter by presenting our lessons for exergame designers, listing the resulting guidelines of this process and discussing how traditional guidelines can be relaxed to achieve action-oriented gameplay in exergames for youth with CP. A home-based study evaluating the games built through this process is presented in Chapter 4.

3.1 Action games

“An action game is one in which the majority of challenges presented are tests of the player’s physical skills and coordination. Puzzle-solving, tactical conflict, and exploration challenges are often present as well” [2]. In most action games, players control an avatar performing a wide set of actions such as walking, jumping, aiming, shooting and throwing items.
Examples of commercial action games include sports games like the NHL series from Electronic Arts (EA) (see Figure 3-1), platformers like Nintendo’s Super Mario World (see Figure 3-1), racing games like Nintendo’s Mario Kart, adventure games like Nintendo’s Legend of Zelda, first person shooters like Activision’s Call of Duty, and fighting games like Capcom’s Street Fighter.

Action games are tremendously popular: in a survey by Kutner and Olson [61], action games represented the top nine favorite games of middle-school boys, and seven of the top ten favorite games of middle-school girls.

We particularly found that action games are a natural fit with exergames, as their rapid pace matches the pace of exercise, and their avatar based gameplay allows full-body inputs such as dancing or cycling. Popular exergames include Konami’s Dance Dance Revolution where players dance frenetically in time to in-game cues, and Microsoft’s Kinect Adventures where players physically dodge, jump and crouch their way through a roller coaster obstacle course (see Figure 3-2).
3.2 Action-oriented exergames and youth with CP

The fast-paced mechanics of action games challenge players’ attention, visual-motor integration and visual-spatial processing skills [100]. These challenges can be barriers to play for youth with CP [40], particularly so in exergames, where the physical challenges of the games are extended to vigorous exercise.

In Chapter 2, we reviewed how youth with GMFCS level III CP might benefit from exergames, and how the majority of youth at GMFCS level III usually fall under the MACS level II categorization. Based on the definition and classification of CP at the GMFCS III and MACS II levels [29,86,91], characterization of action-based games [2,100] and observation of our target population, we found that the main challenges of playing action games are manual ability, gross motor control, visual-motor integration, visual-spatial processing and attention.

Manual Ability

Fine motor skills are needed for manipulating small objects in a controlled manner, such as pressing buttons or manipulating a joystick on a video game controller. Youth with CP have reduced manual ability [91]; those classified at the Manual Ability Classification System (MACS) level II can handle most objects but with reduced quality and/or speed of achievement [29].
Chapter 3: Design for Gameplay Accessibility

Standard game controllers have been used successfully in studies involving youth with CP [25,46]; however, our participants found it hard to use common control schemes. Specifically, participants had difficulties pressing different buttons in rapid succession, using multiple buttons at the same time, or selecting a specific button at exactly the right time. All of these forms of manipulations are required in popular commercial action games.

Gross motor control
Youth at the Gross Motor Function Classification System (GMFCS) level III CP have decreased motor control in both legs [86] and are unable to walk without a mobility aid. Spastic diplegic CP is common in this population, where their legs have decreased selective motor control and their muscles manifest high levels of stiffness, often causing their legs to pull together, turn inward, and cross at the knees [123]. This rules out traditional exercise such as running, jumping or dancing. Cycling-based exercise is possible using a specially-designed recumbent bicycle; however, the CP makes it difficult to pedal smoothly and accurately [46]. We observed that youth with CP find it difficult to start pedaling the bike when it is completely stopped, to provide a sustained, smooth cadence, and to accurately stop at a target location (e.g., a doorway or ladder in the game).

Visual-motor integration
Visual-motor integration measures the degree to which people can coordinate visual stimuli and muscular movements. For example, coordination of visual input and motor actions is required to aim a tennis racquet at an approaching ball. Youth with CP have lower performance in visual-motor integration tasks than youth without CP. Even though eye responses in youth with CP can be as fast as in youth without CP, hand movements are slower and less efficient [92].

This ability is critical in action games for activities such as aiming, dodging, or jumping onto a moving platform [100].
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Visual-spatial processing

Over 83% of youth with CP present seriously affected visual-spatial processing abilities [60]. Visual-spatial processing involves the extraction of spatial information from a visual signal. For example, this skill allows people to develop a mental map of an unfamiliar city by walking around. This skill is important in action games where a player might need to quickly determine the best route through a level, to decide quickly whether two points are close enough together to be able to jump between them, or to decide how much ahead of a moving target to shoot in order to hit it [100].

Attention

During typical development, children habituate motor movement, reducing the attention required to perform common activities such as walking or cycling. Motor habituation is limited in youth with CP [37]. Therefore, when playing an exergame, they must devote considerable attention to required physical movements. This diverts attention from the gameplay itself, rendering games more difficult to play.

Summing up challenges

These limitations call for cautious design, avoiding the need for time-sensitive operations, complex control scheme, and high attention to gameplay. Indeed, existing guidelines for developing games for people with motor disabilities suggest following exactly this approach. However, following these guidelines too literally removes all possibility of real-time action.

3.3 Guidelines for the design of games for people with motor disabilities

There has been wide interest in making games that people with motor disabilities can play. As a result, several sets of guidelines for designing games for people with motor disabilities have been published [20,30,36,42,63,81,121]. These guidelines are the product of experts in game design and accessibility standards.
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Literal interpretation of these guidelines can lead to slow-paced games that are accessible to people with motor disabilities, but may lack the fun of action-based games. A main contribution of this thesis is to show how these guidelines can be relaxed to provide both accessibility and support for action-oriented gameplay. We now describe key guidelines synthesized from these sources and discuss how they steer away from action-oriented gameplay. Throughout this document, we refer to these as “traditional guidelines”.

- *Do not require precise timing* ([30]): avoid the need to make precise movements at a specific time. Much of the fun in platform games such as Sega’s Sonic the Hedgehog and Nintendo’s Super Mario World relies on the player jumping between platforms and dodging enemies’ attacks at the right time. So removing these mechanics would go against their nature.

- *Do not require multiple simultaneous actions* ([30,42,63]): avoid mechanics that require holding buttons down or pressing two at the same time. These mechanics are essential in games like Nintendo’s Mario Kart racing game, where players simultaneously accelerate, steer their kart, and shoot items at other players (see Figure 3-3).

- *Provide a simple control scheme* ([30,42,63,121]): reduce to a minimum the number of

![Figure 3-3: Nintendo's Mario Kart 64.](image)

A player accelerates and steers her kart while shooting an item at the same time.
controls used to play the game, even to only one. This is in stark contrast to action games like Activision’s Call of Duty shooter games, where separate controls are used to walk, run, jump, crouch, aim, shoot, hit, throw grenades, reload, change weapons, activate binoculars, and more.

- **Avoid repeated inputs (button mashing)** [30,63]: do not require rapid consecutive pressing of buttons. This guideline conflicts with the defining nature of action-fighting games, such as Capcom’s Street Fighter, where players punch, kick, block, jump and dodge attacks quickly and consecutively using different buttons (see Figure 3-4).

- **Avoid fast pace** [42]: game elements should move slowly to allow the player time to react. This recommendation conflicts with the fast-paced nature of all action games mentioned above.

- **Automate the player’s input** [121]: reduce the need for detailed control by anticipating the player’s intentions. Examples include steering assistance to avoid obstacles and automatic target lock-on [12].
All but the last guideline conflict with the nature and feel of action gameplay. When applied literally, these lead to slow-paced games without time-sensitive actions and with simple control schemes removing the possibility of a wide space of simultaneous actions. We can see this in the design of exergames intended for people with motor disabilities associated with CP [23,40,83], spinal cord dysfunction [117], stroke [20] and multiple sclerosis [81].

For example, Geurts et al. present four minigames designed specifically for youth with CP [40]. A Wiimote and a webcam are used to track the player’s movement. Each minigame involves a different part of the body. In one of the minigames, Catching Dishes, players extend their hands to catch flying dishes at the edge of the screen and pile them in the middle. The dishes are thrown quickly from the center of the screen and then remain at the end position during a long period of time, so that the players can reach them without having to rush. This minigame follows the first five traditional guidelines.

As a second example, the Virtual WiiHab System combines physical actions using a Wiimote and a Wii Balance Board for rehabilitation of the lower body [4]. Four minigames aim to increase trunk control, lower extremity stability and balance. In each minigame the players use the Wii Balance Board to navigate a virtual environment. Three of the games require accuracy of movement on the Wii Balance Board instead of quick reactions. One game is more action-oriented, requiring quick movement on the balance board to avoid incoming snowballs and using the Wiimote to throw snowballs back. The first three minigames follow the first five traditional guidelines.

The use of traditional guidelines is the correct choice in these two examples. In rehabilitation games focusing on stretching and balancing actions, frenetically fast-paced gameplay is not appropriate. Additionally, following these guidelines can make games that are accessible for a wider range of people, expanding the user group that can benefit from them. However, games encouraging vigorous cardio-vascular exercise should not be slow-paced, but instead should
match vigorous action on the part of the player to fast action in the game. This has led us to explore principled ways of relaxing these guidelines to allow increased action-oriented gameplay while retaining accessibility. We now describe how we achieved this goal.

3.4 Design of an action-oriented exergame for youth with CP

To address the challenge of designing action-oriented exergames for youth with CP, we decided to explore their capabilities to play action-oriented games rather than literally following the recommendations of traditional guidelines.

3.4.1 Design method

We approached our design challenge through a participatory, iterative design process. Over the course of a year, we conducted seven participatory design sessions in which we brought together a group of youth with CP and a multi-disciplinary research group including a pediatrician specializing in youth with CP, a physiotherapist, computer scientists, and a mechanical engineer. We also received offline advice from an exercise psychologist, a kinesiologist and a professional game designer.

3.4.2 Goals

This research was conducted in the context of a broader project exploring the health and social benefits of exergaming for youth with CP. Our participatory design sessions covered four aspects of the development of an exergame for youth with CP, of which two are the focus of this thesis.

The goals related to this thesis are:

1. To design and evaluate an action-oriented exergame that youth with CP can play. All seven sessions included activities associated with pursuing this goal. A resulting set of guidelines for the design of exergames for youth with CP and their implementation in the context of an exergame are main contributions of this thesis and the focus of this chapter.
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2. To design an online game that allows social interaction for youth with CP. This is another main contribution of this thesis, and is elaborated in Chapter 5.

Other goals covered during the sessions:

3. To design and evaluate an exergaming station that allows youth with CP to provide moderately vigorous input to our exergame. During the first four sessions of our design process we dedicated part of our time to testing prototypes of the exergaming station with our participants to make sure it allowed the players to transition from their walkers or wheelchairs to the station, to pedal unassisted, and to reach moderate levels of exertion. The final station was used by all the participants for the last three sessions.

4. To design and evaluate an exergame that promotes cardiovascular exercise of youth with CP. The pediatrician and physiotherapist of our team participated in our design sessions, providing their knowledge to make the exergame relevant for therapeutic purposes.

3.4.3 Personnel, responsibilities and contributions

Our design sessions were influenced by the multidisciplinary research group which contributed greatly to achieving the different goals of our project. The contributions of each member of this group were described in detail earlier in section 1.5. Our participatory design sessions were attended by my supervisor and the following members of our team:

- Dr. Darcy Fehlings, who provided her expertise in youth with CP to guide our design and evaluation sessions. All our sessions were attended by Dr. Fehlings and/or members of her team.

- Lauren Switzer, who managed the logistics of scheduling participants and a space at the hospital to conduct our design sessions and made sure that the necessary equipment was available for the sessions.

- Dr. Virginia Wright, who provided expert guidance on the capabilities of youth with CP and attended some of our design sessions.
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- Mr. Bill Johnson, who attended the design sessions where the exergaming station was tested with our participants.

- Zi Ye, who was in charge of implementing the game ideas resulting from initial design sessions and group meetings and that were tested throughout the whole process. Mr. Ye also attended the design sessions where the usability and enjoyment of the game were evaluated.

My role in this participatory design process was to work together with Dr. Fehlings’ team to plan, set up and execute our participatory design sessions and home-based evaluations with youth with CP. I facilitated data collection tools such as custom questionnaires and interviews scripts for eliciting feedback and new requirements in terms of accessibility and enjoyment of the games during the sessions. I worked closely with Zi Ye at our lab, to guarantee that the game addressed the identified requirements and to make sure that the game was instrumented to collect necessary data during our sessions and home-based evaluations. I also contributed game ideas and alternatives to address accessibility and enjoyment requirements. I personally took the lead in conducting the design sessions at the hospital, analyzing collected quantitative and qualitative data and reporting findings to the research group.

3.4.4 Participants

Our participatory design sessions included a group of ten youths with CP. Three of these participants were female and seven were male. The mean age was 15.2, with a minimum of 12 and maximum of 18. Seven had spastic diplegia (the lower limbs are affected) and three had spastic triplegia (lower limbs and one arm are affected). Nine were at GMFCS level III, where the main form of mobility is with the use of a walker, and one was at GMFCS level IV, where a manual wheelchair is required. One participant was at MACS level IV, one was at level III, three were at level II and five at level I. Some of the participants were accompanied by their guardians.
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3.4.5 Equipment

Each design and evaluation session required the use of a cycling exergaming station to allow our participants to interact with our exergame, and networking equipment to establish a private local network for the game.

During the first four sessions, our participants used an early prototype of our exergaming station consisting of a conference chair, a pedaling unit with wooden frames and Velcro to keep the participant’s feet in place, and a wooden frame keeping the pedaling unit and chair together (see Figure 3-5). Each participant had at least one person from our team with them to aid their stability on the chair. The final station, which we call the Racer Bike, was ready to be used starting the fifth session. The Racer Bike (Figure 3-5) is custom-designed for people with motor disabilities, featuring pedal supports, lateral supports, low handlebars allowing easy entry and exit, a seatbelt, and special non-slip material on the seat. In front of the bicycle, an adjustable stand holds a 23” all-in-one Toshiba computer. Our participants proved capable of transferring from a walker or wheelchair to this unit and engaging in vigorous pedaling activity.

In addition to the bike, players used a Logitech F710 game controller, and a Polar chest strap heart rate monitor combined with a Sparkfun Heart Rate Monitor Interface (HRMI) receiver circuit taped to the back of the seat, which provided the game with information about the vigour

![Figure 3-5: Early prototype and final version of the exergaming station.](image)

Left: Early prototype of our station. Right: the Racer Bike, final exergaming station.
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put into playing. The estimated total cost of the equipment necessary to play the games (exergaming station, computer and peripherals) is $2,000.00 Canadian dollars.

3.4.6 Setup

All seven of our sessions were conducted at HBKRH in a spacious room where we were able to arrange three stations connected to a local wired network, as shown in Figure 3-6. Due to availability of our specialized equipment, participants were scheduled in groups of three separated by two hours. For most of the sessions, we had a total of six participants.

Research assistants from the hospital and the EQUIS lab also attended these sessions, supporting the team during the setup of the room and the stations and helping participants move around the room, transfer to the station, and put the heart rate monitors on. They also helped us in applying game questionnaires and interviewing the participants.

3.4.7 Development of the sessions

In early design sessions we had group discussions with our participants from which we learned about their abilities, gaming experience, and preferences for game features. A few of our

![Figure 3-6: Participatory design session at Holland Bloorview Kids Rehabilitation Hospital.](image)

Three children with CP play our game on the racer bike, while members of the team and research assistants observe them play and take notes about their feedback and playability issues.
participants’ guardians provided information about the capabilities and difficulties of the participants when playing video games at home. Through brainstorming sessions, participants provided ideas of games and drawings of characters. We adapted and included these in the game. We discovered that our participants had an overwhelming preference for action games, strongly influencing their game design ideas. This reaffirmed our motivation to try to design action-oriented exergames playable by this user group.

During subsequent sessions we asked the participants to play early prototypes of our game to test its usability, playability and fun, and we gathered feedback from the participants by applying a custom designed Likert scale questionnaire (see Appendix 1: Playability and enjoyment Likert scale questionnaire for participatory design sessions) and a semi-structured interview. After each design session we returned to our lab in Kingston to analyze the data collected, and to come up with solutions for the identified issues and make the necessary adjustments to the game. Then we got ready for follow-up iterations with the youth at the hospital, until the games were ready for a home-based evaluation, described in chapter 4.

3.5 The Liberi exergame

The game’s title, “Liberi”, comes from the Latin word for “the free people”. The goal of Liberi is to allow youth with CP (GMFCS level III) to participate in vigorous physical activity while socializing with friends. Liberi is played using our stationary recumbent bicycle and a standard Logitech wireless game controller, as shown in Figure 3-8. They aim with the left joystick and invoke game actions with the A button. Liberi was implemented using the Unity game engine.

The game takes place on Liberi Island, a persistent world that allows a small group of players to meet up and play action-oriented minigames together. The island provides a central plaza (Figure 3-7) that gives access to different regions containing minigames and to various shops where players can purchase rewards such as costumes, weapons and crafting materials using coins gained from long-term play of minigames.
There are six minigames in total, three of which are discussed in detail below. Each minigame has a different style of gameplay, including a platformer game, a competitive racing game, a zombie defense game, a space-based hockey game, a fighting game, and a cooperative round-up game. Players pedal the recumbent bicycle to move their avatars. Liberi provides a voice communication system that allows players to invite each other to the different minigames, coordinate cooperative play, cheer or taunt each other, or simply chat.
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3.5.1 Findings

From our experience designing and testing these action-based exergames, we found that it is possible to build action-oriented exergames that youth enthusiastically play while following the spirit of the traditional design guidelines. For example, a game can have fast-paced action and time sensitive and rapid interactions as long as the impact of play errors is low, the flow of the level is forgiving, and the control scheme is simple.

We now describe a representative selection of three of these minigames. Each minigame went through several iterations of design and testing, evolving significantly by improving its playability. These sections illustrate by example how it is possible to overcome the challenges of building action games for youth with CP, describing in detail our design decisions.

3.5.2 The Dozo Quest minigame

In Dozo Quest, players control living spiky balls which roll and dash their way through a maze in the desert. The desert is filled with enemies, obstacles, traps, and loot for the player to collect. The player can perform a “dash” attack, which is used to jump over obstacles and to damage enemies. We also included a powerful boss at the end of the minigame which the players can defeat alone or in group. Figure 3-9 shows three players playing Dozo Quest.

How Dozo Quest is an action game

Dozo Quest uses mechanics typical of action games. Players control an avatar in real-time. The

![Figure 3-9: The Dozo Quest minigame.](image)

Left: one player advances through the level. Right: three players fight the final boss.
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dash ability allows the avatar to jump over chasms or to fight enemies. Dashing must be carefully timed to avoid falling from a platform or being swarmed by enemies. The game level includes moving platforms and obstacles that require rapid jumping and dodging; enemies spawn in real-time and must be killed quickly to allow progress, and there is a climactic boss fight where players must time their attacks, dodge the boss’ attacks, and cooperate with other players.

Why creating such a game is challenging

Dozo Quest’s gameplay requires skills that are impacted by CP. Specifically, the first version of the game involved all of the following challenges:

- It is difficult to time jumps and dashes and to dodge enemies. These actions require the use of manual ability and visual motor integration.
- It is difficult to rapidly select between multiple actions via a game controller.
- It requires great concentration to pedal a bicycle smoothly, making it difficult to navigate platforms and ramps and to avoid enemies. Pedaling involves gross motor skills and diverts attention from the game itself.
- It is difficult to navigate a 2D maze which is only partially visible and which offers multiple possible paths. This requires visual-spatial processing.

As we will see, careful design around the abilities of youth with CP mitigated these problems. The first version of Dozo Quest included all of these problematic mechanics. In our first testing session with the game, some of the participants could play for only a few tens of seconds until they could not advance further and gave up. To allow longer testing of the game, we helped them pass sections of the level that were particularly difficult for them. When we asked them whether they found this version of the game easy to play, only two participants agreed (score of 4 or higher on a 5-point scale), one was neutral and three disagreed (score of 2 or lower) (Figure 3-10). They commented on this experience saying: “I had some trouble with it, because of the fact that you had to boost to get on the pyramid, and also that I had to pedal fast enough sometimes to
Despite playability issues, participants reported having fun with this first version of the game and found the game challenging (five participants agreed and only one was neutral, in both cases), and all of them reported that the game was physically tiring, confirming that this game could be effective at motivating moderate levels of exertion.

**What special measures make the game playable**

Following iterative design and evaluation of Dozo Quest, we identified four recommendations that help overcome the difficulties that youth with CP face when playing platform games:

- *Simplify level geometry:* The core of a platformer game is the navigation of a maze of ramps, trap doors and obstacles in real-time. This gameplay can be preserved by careful
design of the game level. Platforms and obstacles should be static. Ramps should have high friction so that players do not slide down quickly when attempting to time jumps.

- **Simplify level flow:** the level should have few branching points to reduce the need for decision-making and to reduce the importance of building a mental model of the level’s design. When the level does branch, the branching paths should rejoin later so that all paths lead to the same place. This can give the illusion of a complex level while actually providing linear gameplay.

- **Reduce consequences of errors:** the punishment for making errors in gameplay should be low. For example, players who mistime a jump should not fall to a lower part of the structure that requires them to replay several minutes to return to the point of the error. Players should not die as a consequence of mistiming attacks on an enemy, requiring them to return to a checkpoint much earlier in the level.

- **Limit available actions:** at any time, only a limited number of actions should be possible. Other than the actions required to move the avatar (pedaling and selecting a direction with a joystick), at most one other action should be available. This simplifies the range of possible decisions, and simplifies the control scheme by removing the need for multiple active buttons on the game controller.

**Results**

We modified Dozo Quest according to these principles. The level geometry and flow were significantly simplified. Most moving platforms were turned into static platforms. Ramps were less slippery, giving the players time before they slide to the bottom. The increased friction allows players to reach the top of ramps without using the “dash” ability (although dashing makes it faster to reach the top). The level includes only a few branch points. Branches provide an easy and a hard route; these are signposted and all lead to the same place. When players miss a jump, they fall to a location from which it is easy to get back. At the bottom of drops, signposts show
which direction should be followed, so players do not get lost. Only one special action is possible, the “dash” ability, which is invoked by pressing the “A” button on the controller. The game determines from context whether this action should be interpreted as a jump, a sprint up a ramp, or an attack on an enemy.

As we will see in the next chapter, these changes to the game improved the playability of the game, attracted significant attention to it and allowed all the players to play and complete the level.

3.5.3 The Bobo Ranch minigame

In Bobo Ranch, players control birds that are in charge of quelling a sheep rebellion on a ranch (Figure 3-11). In the initial version of the game, players honk loud horns at the sheep, scaring them into flying back to a barn. To move a sheep, a player flies close to it by pedaling her bicycle, aims her horn at the sheep, and presses the “A” button on her game controller to release a loud “honk!” The player pedals back to the ranch, honking all the way to keep the sheep moving in the right direction. Once the sheep reaches the ranch building, it disappears inside, and the player is awarded money. The sheep have different behaviors such as indifference, fleeing, or

![Figure 3-11: First version of the Bobo Ranch minigame.](image-url)
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retaliation, each requiring a different aiming strategy. Players are rewarded with a bounty for every sheep they return to the barn. Two players can push the same sheep, increasing its speed. Bonus bounty is given for cooperation.

*How Bobo Ranch is an action game*

Bobo Ranch requires rapid movement, aiming, fleeing, and coordination with other players, all gameplay associated with action games. The sheep are mobile, requiring the players to move quickly to catch and aim at them, or to run away from aggressive enemies. Players need to rapidly coordinate with other players to select which sheep to “honk” back to the ranch.

*Why creating such a game is challenging*

Some of the mechanics in this type of game are difficult to perform for youth with CP:

- It is difficult to quickly position the avatar close to the sheep, pointing in the correct direction. This requires both manual ability and gross motor skills.
- It is hard to visualize which sheep will move due to honking and in which direction. This requires visual-spatial processing skills.
- It is hard to follow other players in order to effectively collaborate. This requires significant attention to the gameplay, visual-spatial skills (to anticipate other players’ actions), and gross motor skills (to quickly follow other players).

One participant raised the difficulty of collaborating with other players: “one person is doing all the work… basically you [are] on your own, [be]cause the feel of the cooperative is not really like cooperative”. One participant’s mother pointed out the attention difficulty: “They were working together but not realizing it, [be]cause they are concentrating on their own”.

Players enjoyed Bobo Ranch, even in this early version. Five participants agreed that they had fun playing it, and a sixth participant felt neutral about it (Figure 3-12). However, the players’ difficulty in collaborating indicated that redesign was required. The players were also divided about whether the game was challenging (three agreed it was, one was neutral about it and two
disagreed,) and whether it was physically tiring (two agreed it was, one was neutral, and three disagreed).

What special measures make the game playable

By testing with the youth during our participatory design sessions, we identified two recommendations that helped solve the game’s difficulties:

- **Remove need for precise positioning and aiming**: The game should not require players to precisely position their avatar or to precisely aim at a target.

- **Make game state visible**: The game should use visual cues to clearly indicate the effect that potential actions would have, to show other players’ locations and actions.

**Results**

We modified Bobo Ranch to take into account these two recommendations. The resulting game is shown in Figure 3-13. Rather than requiring players to precisely position and aim their horn, we introduced the mechanic of a lasso. To bring a sheep to the ranch, the player now moves close to the target sheep and presses the “A” button. All sheep within the lasso’s radius are captured with a rope. The player then drags the sheep back to the ranch. The lasso’s radius is centered on the
player’s avatar, meaning that the player no longer needs to aim directionally. The radius is large enough (and increases if the player pedals harder) that precise positioning is not required.

To reduce the attention required to understand the game state, visual cues were added. The lasso shows which sheep would be captured by pressing the “A” button. Ropes show which sheep each player is pulling. These ropes help clarify both the player’s own state as well as that of other players. Pictures on the border of the screen show the direction of players who are currently off-screen, helping players find each other. Figure 3-13 shows Player 1 pulling three sheep towards the barn (one of them in collaboration with Player 3), and Player 2 getting ready to throw a lasso. Two additional players are off-screen to the east and to the north.

In the next chapter we will see that the refined version of Bobo Ranch was received positively, allowing all players to play cooperatively with the others.

3.5.4 The Gekku Race minigame

In Gekku Race, players race to be the first “gekku” lizard to reach the top of a wall. Players can spit cashews at other players to stun them, or breathe fire on their opponents to cause them to lose their grip. Once a player reaches the top, the round ends, and all of the gekkus slide down the wall.
to prepare for the next round. The players are rewarded with one gold coin for every meter they fall. Figure 3-14 shows two players performing different attacks.

**How Gekku Race is an action game**

Gekku Race mixes qualities of racing and shooter games. It involves control of an avatar in real-time, racing against others to the end of a track, attacking other players with special attacks, and dodging other players’ attacks.

**Why creating such a game is challenging**

Some of the mechanics in this type of game are difficult to perform for youth with CP:

- It is difficult to aim at others. This requires manual ability and visual-motor integration.
- It is difficult to dodge others’ attacks. This involves gross motor skills (to move the avatar out of the way), manual ability (to aim the avatar in the correct direction) and visual-spatial processing (to understand how a cashew will move and bounce over time).
- It requires great concentration to simultaneously follow a track at maximum speed, hit power-ups, avoid obstacles, and avoid other players at the same time. All of these features are commonly found in racing games.
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What special measures make the game playable

To make Gekku Race playable by youth with CP, we employed three rules. The *simplify level geometry* rule is adopted from the Dozo Quest game. *The remove need for precise positioning and aiming* rule is adopted from the Bobo Ranch game. One new rule is used:

- **Balance the game for differing abilities:** Players with CP differ significantly in their physical abilities, even within the GMFCS III classification. In a racing game, even small differences in ability to pedal can result in always winning or always losing. The game must balance player input so that people making similar effort can move at similar speed.

**Results**

Gekku Race was designed to meet these three recommendations. The level geometry is simplified: unlike most racing games, the track is designed as a simple, straight line. There are no obstacles for players to dodge and no curves to navigate. There are no collisions between players, removing the need to navigate around traffic jams.

While players can attack each other, the mechanics are designed to not require precise aiming. Avatars are large. Cashews move slowly allowing time to dodge them. The flame attack covers a wide area, making it easy to aim.

To help balance the game, the parameter mapping the bike’s cadence to the avatar’s speed can be individually set for each player.

Gekku Race’s playability and enjoyment was high even in this early version. Five participants agreed that it was easy to play while a sixth participant was neutral about it, and all of them had fun playing it and found it physically tiring (see Figure 3-15).

**3.6 Lessons for designers**

Our core lesson is that it is possible to create action-oriented exergames that can be played and enjoyed by youth with CP at GMFCS level III. Traditional design guidelines, when applied
directly, encourage the design of slower games with less action. Considering our population’s special abilities, our design recommendations preserve the core message of traditional guidelines, while mitigating some of their effects.

To summarize, our new design recommendations are:

- **Simplify level geometry**, reducing the need for carefully timed actions to navigate the game world.
- **Simplify level flow**, reducing the number of decisions players need to make and reducing the demands on visual-spatial reasoning.
- **Reduce consequences of errors**, ensuring that errors due to difficulties completing rapid or time-sensitive actions do not impair fun.
- **Limit available actions**, reducing the number of decisions players need to make, and enabling a simpler control scheme.
- **Remove the need for precise positioning and aiming**, reducing the demands on manual ability and visual-motor integration.
- **Make the game state visible**, reducing the need for attention to gameplay, and reducing the need for visual-spatial reasoning to deduce game state.
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- **Balance for effort**, compensating for the differences in players’ gross motor skills.

These recommendations echo ideas found in the traditional guidelines, which we now recap, but allow them to be applied in a nuanced manner:

- **Games should not require precise timing.** Time-sensitivity is acceptable as long as the level geometry, control scheme and consequences of errors are carefully designed. For example, in Dozo Quest, it was possible to create a game involving climbing and jumping, as long as the ramps had high friction, the control scheme was simplified by providing only one choice of special ability, and errors such as failing to make a jump carried only modest penalties. Similarly, in Gekku Race, players fire at each other and dodge, but precise timing is not required since the targets (other player’s avatars) are large, the missiles (cashews) move slowly and are therefore possible to dodge, and the flame attack has a wide arc of fire, requiring little aiming. The penalties for being hit are recovered in seconds, causing more laughter than frustration.

- **Games should use a simple control scheme that does not require simultaneous actions and that avoids repeated inputs.** Action games are frequently characterized by “button mashing” in which all 12 buttons, triggers and joysticks of a typical game controller are simultaneously active. Simplifying the control scheme risks reducing the complexity and range of choice in the game, rendering it boring. We discovered that this guideline could be followed while retaining the flavor of an action game. In all minigames, players can move by pedaling, aim with a joystick, and access a single special ability (with the controller’s “A” button.) We take Yuan’s advice to “automate input” [121] by using game context to determine the effect of that special ability. E.g., in Dozo Quest, the player’s direction determines whether the “dash” ability is a jump, a sprint or an attack on an enemy.
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- Avoid fast pace. Action games are defined by their fast pace. By following our recommendations, games can allow players to rapidly navigate and interact with their environment. Simplifying level flow and making the game state visible help reduce the need for quick decision making, allowing players to focus on moving their avatar. Removing the need for precise positioning and aiming allows shooting and racing activities to be performed more quickly.

In sum, our recommendations provide ways of achieving the intent of traditional guidelines while still permitting action-oriented play.

One important design issue not covered by traditional guidelines is that the players experience difficulty in pedaling, distracting their attention from the game. Our recommendations mitigate this problem by reducing the attention required by the game itself.

After our year-long participatory design process, we developed three more action-oriented minigames at our lab using our new game design guidelines. The new minigames were Biri Brawl, Wiskin Defense and Pogi Pong.

In the first version of Biri Brawl, players play reverse tag controlling jellyfishes in a pond. The goal of the game is to remain “it” for as long as possible. At the beginning of the game, a random player is “it”, and the other players have to get close to her and press the action button to zap her and become “it”. This game involves steering the Jellyfish under the water with the joystick, pedaling the bike to move and pressing the action button to zap the player who is “it”.

In Wiskin Defense, players defend a group of cute penguin-like creatures in a cave from a horde of zombies. Players walk left and right in the cave steering with the joystick and pedaling the bike and use a melee or long range weapon to whack or shoot at the approaching zombies by pressing the action button.
In Pogi Pong, players control hedgehogs in space. Players are split into two teams competing to knock a star into the opposing team’s goal. The team that scores the most goals wins. In this minigame, players press the action button to accelerate their hedgehogs and push the star forward.

Table 1 presents a summary of our guidelines for the design of action-oriented exergames for youth with CP with two examples of how each guideline was implemented in our minigames.

The following chapter describes the details and results of a home-based evaluation of our exergame in which the final versions of the three action-based minigames designed throughout our participatory design process and two of the three minigames developed later at our lab were evaluated for playability and enjoyment over eight weeks.
Table 1: Examples of the implementation of our design guidelines for accessible gameplay.

<table>
<thead>
<tr>
<th>Guideline</th>
<th>Example 1</th>
<th>Example 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simplify level geometry</td>
<td>In Dozo Quest, platforms were made static and ramps had high friction reducing the need to precisely time jumps.</td>
<td>In Gekku Race, the track is linear, with no obstacles or collisions between avatars, removing the need to steer.</td>
</tr>
<tr>
<td>Simplify level flow</td>
<td>In Wiskin Defense, zombies spawn only from the left or right walls towards the centre. Players do not need to navigate a complex level to find their enemies.</td>
<td>In Dozo Quest, the level has few branching points, reducing the need for decisions and for building a mental model of the level’s design.</td>
</tr>
<tr>
<td>Reduce consequences of errors</td>
<td>In Dozo Quest, failing to jump a gap allows the player to quickly try again without having to navigate a long section of the level again.</td>
<td>In Wiskin Defense, if players miss hitting a zombie, they can quickly chase it and try to hit it again.</td>
</tr>
<tr>
<td>Limit available actions</td>
<td>In Dozo Quest, only the “dash” ability is available, invoked by pressing the “A” button on the controller. The game determines from context whether this action should be a jump, a sprint up a ramp, or an attack on an enemy.</td>
<td>In Wiskin Defense, players have only one attack available using the action button. Depending on the weapon selected, the player will either whack or shoot at a zombie.</td>
</tr>
<tr>
<td>Remove the need for precise positioning and aiming</td>
<td>In Bobo Ranch, players can capture sheep by moving close to them and pressing the action button, without needing to precisely position their avatar or to precisely aim at the sheep.</td>
<td>In Gekku Race, avatars are large. Cashews move slowly allowing time to dodge. The flame attack covers a wide area, making it easy to aim.</td>
</tr>
<tr>
<td>Make the game state visible</td>
<td>In Bobo Ranch, players see other players’ lassos allowing them to see what sheep other players are trying to capture. This helps players to coordinate and work together.</td>
<td>In Wiskin Defense, players can easily see how close to the Wiskin the zombies are and where the other players are located, allowing them to coordinate the defense.</td>
</tr>
<tr>
<td>Balance for effort</td>
<td>To help balance the game, a parameter maps the bike’s cadence to the avatar’s speed. This parameter can be individually set for each player.</td>
<td></td>
</tr>
</tbody>
</table>
Chapter 4

Evaluation of Liberi’s Action-oriented Minigames

Liberi has been evaluated over three home-based studies, two of which were aligned with the two hypotheses of this thesis:

- The first study addressed the first hypothesis: *By using game design guidelines for gameplay accessibility, it is possible to design exergames that youth with CP can play and enjoy.* In this study, we evaluated the long-term playability and enjoyment of five action-oriented minigames that were built according to the design guidelines described in Chapter 3. This study serves as a means of evaluating the effectiveness of our design guidelines in producing action-oriented exergames that youth with CP can play and enjoy. The details of this study are the focus of this chapter.

- The second study focused on the evaluation of Liberi in enabling levels of exercise that could lead to improvements in cardiovascular fitness for youth with CP. This study was conducted in accordance with the therapeutic goals of a broader project analyzing the health and social benefits of exergaming for youth with CP. This study was not aligned with and did not contribute to the hypotheses studied under the scope of this thesis and therefore is not reported in this document.

- The third study addresses the second hypothesis of this thesis: *By following design guidelines for social accessibility, we can allow youth with CP to socially interact with other youth through video games.* This study is elaborated in Chapter 6.

The following sections of this chapter present the details and results of the first home-based study evaluating the playability and enjoyment of our action-oriented exergames for youth with CP.
Chapter 4: Evaluation of Liberi’s Action-oriented Minigames

4.1 Evaluation of the playability and enjoyment of Liberi

We performed a prospective case study with a single experimental group, where participants played Liberi from home over eight weeks.

For this study, Liberi provided six minigames spread over six regions of the virtual world. Three of these minigames (Dozo Quest, Bobo Ranch, and Gekku Race, described in Chapter 3) were designed throughout our participatory design process. Two new minigames, Biri Brawl and Wiskin Defence, were designed after our participatory design process making use of our new guidelines for the design of exergames for youth with CP.

The sixth minigame, Mansion Deco, was not an action-oriented game and was not designed using our guidelines. In this minigame, each player was given a mansion that they could decorate with furniture and trophies crafted from resources obtained by playing the other five minigames. Mansion Deco allowed players to make their achievements in the game public to the other players.

4.2 Goal

The goal of this first study was to evaluate the effectiveness of our design guidelines in producing exergames that youth with CP can play and enjoy. To achieve this goal, we performed the following activities:

- Evaluation of the playability and enjoyment of minigames resulting from our participatory design process (Dozo Quest, Bobo Ranch and Gekku Race) over an eight-week term; and

- Evaluation of the playability and enjoyment of two more minigames built after the participatory design sessions (Biri Brawl and Wiskin Defense) making use of our guidelines for the design of exergames for youth with CP.

An additional activity outside the scope of this thesis was the evaluation of the effectiveness of Liberi in allowing youth with CP to reach moderately vigorous levels of exercise.
Chapter 4: Evaluation of Liberi’s Action-oriented Minigames

4.3 Participants

Four of the original ten youths with CP who took part in our participatory design process and one new participant were recruited for this study. Our five participants were at GMFCS level III, two were at MACS level II and three were at MACS level I. The mean age was 15 with a minimum of 13 and a maximum of 17; one was female and four were male.

4.4 Setup of the study

In accordance with the therapeutical goal of designing an exergame that motivates exercise levels that might produce cardiovascular improvements for youth with CP, an exercise prescription for participants of this study was designed. This prescription was prepared by Dr. Darren Warburton, professor in kinesiology at the University of British Columbia, who has worked on creating exercise programs for people with motor disabilities and is one of the authors of the Canadian Society for Exercise Physiology - Physical Activity Guidelines for Canadians; Dr. Ryan Rhodes, professor in exercise psychology at the University of Victoria, who conducts research on physical activity and health; and Dr. Darcy Fehlings and Dr. Virginia Wright, experts in CP at Holland Bloorview Kids Rehabilitation Hospital (HBKRH).

This exercise prescription suggests a minimum of three sessions of physical activity per week, reaching moderately vigorous levels of exercise. Players were recommended to accumulate a minimum of 30 minutes of activity per session for the first four weeks of the intervention; 35 minutes per session for weeks six and seven; and 40 minutes per session for the last two weeks (see Appendix B). This prescription defined moderately vigorous exercise as exercise at an intensity that elevates a person’s heart rate to their resting heart rate plus 40% of their heart rate reserve ($HR_{reserve}$: the difference between a participant’s maximum heart rate and resting heart rate). We called this value the target heart rate ($HR_{target}$).

Before the beginning of the study, all participants attended a preparatory session at HBKRH. During this session, for each participant, the resting heart rate was measured and a proper
Chapter 4: Evaluation of Liberi’s Action-oriented Minigames

resistance of the bike was determined that allowed them to pedal unassisted while providing enough challenge to encourage moderate levels of exertion. Both of these procedures were conducted by research assistants under the supervision of Dr. Darcy Fehlings, Physician Director at HBKRH, who specializes in youth with CP.

Using the measured resting heart rate and the Karvonen formula [114], the target heart rate for each participant was calculated:

\[ HR_{target} = (HR_{reserve} \times \text{%intensity}) + HR_{rest} \]

where \( HR_{reserve} = (HR_{max} - HR_{rest}) \)

We used a maximum heart rate of 194 beats per minute, formalized as a more precise estimation of maximum heart rate for children and adolescents with CP than the estimations of traditional age-based formulas [109].

A research assistant from HBKRH and I then set up an exergaming station at each of the participants’ houses. We gave instructions to the families about how to start and finish a daily game session. Printed manuals were given to the families showing how to wear, connect and turn on each of the peripherals used by our game. A wireless connection was setup for the computer, and where necessary, a long Ethernet cable was provided to connect the computer directly to the network router to improve Internet quality. The resistance of the bike and the parameter mapping the bike’s cadence to the game avatar’s speed were set for each participant according to the measurement conducted at the hospital.

During the study, the game server was open daily for a 1.5 hour period to give higher chances for the participants to meet online. The participants were free to determine when (and whether) they wanted to play, but were recommended to follow the exercise prescription provided. Three minigames were available initially, and the other three were introduced on two week intervals. Gekku Race, Biri Brawl and Mansion Deco were the opening games, available from the first day. Dozo Quest was introduced for the second half of week two; Bobo Ranch was introduced on the
Chapter 4: Evaluation of Liberi’s Action-oriented Minigames

second day of week five, and finally Wiskin Defense was introduced at the beginning of week seven.

Each gaming session was supervised by a “game monitor” research assistant trained to troubleshoot technical difficulties with the hardware devices used to play the game or with the game itself. The game monitors were included in the game’s voice channel to facilitate participants asking for help or reporting bugs in the game.

A technical support line was made available for participants to call in case of experiencing major technical issues that prevented them from using the computer or connecting to the Internet when trying to play the game. The game monitors were given a pager to be notified of the issues reported through the technical support line and were instructed to call the participants back if necessary.

In addition, starting from the third week, a research assistant from the hospital phoned each participant weekly to review their participation, to encourage them to meet the goals determined by the exercise prescription, and to identify whether adjustment to the resistance of the bike was necessary.

4.5 Data collection

During this intervention we collected quantitative and qualitative data. In terms of quantitative data, the game was instrumented to automatically record participants’ actions. Each game client created a log file with the player’s heart rate, pedaling cadence, avatar’s position in the virtual world, and minigame they were playing every second. Events such as button presses and the result of interactions with game elements were also inserted in the log as they occurred. Subjective data included a custom Likert scale questionnaire gathering the participants’ feedback and experience playing the minigames.
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In terms of qualitative data, we conducted a personal interview with each participant collecting information about their experience with each minigame.

In addition to this data, the game monitors took notes of the events related with hardware failures or software bugs that happened during each session. A private Facebook group was also created to allow participants of the study to communicate between each other to schedule times to play together, and to communicate with the game monitor to report technical problems or ask questions about features of the game.

4.6 Results
In terms of the playability and enjoyment of our action-oriented minigames, we found positive results evidenced by both a significant amount of time the players were active in the game and in each of the minigames (measured as time players were pedaling the bike) and positive feedback gathered through our Likert scale questionnaires and semi-structured interview. For each of the minigames, we discuss how we can assess the success of our design guidelines.

We include the Mansion Deco minigame in the graphs below, but this minigame is not analyzed in depth since it does not contribute to the analysis of playability of action-oriented exergames for youth with CP or the effectiveness of our guidelines.

4.6.1 Playability and engagement
Participants played 174.4 minutes per week on average (Standard Deviation (SD): 45.4), in line with the prescribed amount of a minimum of 90 minutes per week (Figure 4-1). This number of minutes includes the time the participants were playing the minigames and also navigating the island. An encouraging result was that our participants played more minutes during the last week than the first, indicating high engagement with the game. At the end of the study, on average, participants had accumulated 1,395.1 minutes playing (see Figure 4-2).
In terms of the playability and enjoyment of each minigame, our action-oriented minigames were played at least 50.4 minutes on average (see Figure 4-3). The minigames Gekku Race, Wiskin Defense and Dozo Quest received higher attention than the others despite the order they were released during the study. For example, Gekku Race, available from the first week, accumulated the highest number of minutes over the trial (661 minutes), followed by the game Wiskin Defense (235 minutes), which was available only over the last two weeks. The amount of minutes that each game was played indicates that both the action-oriented minigames developed
during our participatory design process (Gekku Race, Dozo Quest and Bobo Ranch) and the ones developed after the participatory process making use of our design guidelines (Biri Brawl and Wiskin Defense) were playable by this population.

The time listed as “Out of minigames” includes time traveling around the virtual world to go from one minigame to another, time spent in the shops of the central plaza and idle time (not interacting with the game).

Given that each minigame was available a different number of weeks, the total minutes in each minigame (as shown in Figure 4-3) does not convey how popular each game was. A closer representation of the popularity of each game is shown in Figure 4-4, where the total minutes per minigame has been divided by the number of weeks each game was available, resulting in the average weekly minutes per minigame. Here we can see that Wiskin Defense was the most popular game, followed by Gekku Race. Gekku Race and Biri Brawl were available eight weeks, Dozo Quest 6.4 weeks, Bobo Ranch 5.9 weeks and Wiskin Defense two weeks.

Figure 4-5 shows the preference of each minigame over the course of the eight weeks. Here we can see how Gekku Race was particularly successful at remaining the game of choice over the course of seven of eight weeks, losing only to Wiskin Defense during the last week.
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It should be taken into account that the graphs showing the attention received by each minigame are all influenced by the order in which each minigame was introduced to the study.

The following sections analyze in detail how each of the action-oriented minigames was accepted by the participants and how engaging the minigames were over the length of our study.

4.6.2 The Gekku Race minigame

Gekku Race had been previously found playable and fun during our participatory design and evaluation sessions. To make Gekku Race playable for youth with CP, we designed it with three
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of our design guidelines in mind: simplify level geometry, remove need for precise positioning and aiming, and balance the game for differing abilities. For this home-based trial, Gekku Race was available for all eight weeks.

Evidence of the playability achieved by the game during this home trial can be seen in the fact that participants played Gekku Race an average of 82.6 minutes/week, as we showed in Figure 4-4. Gekku Race was highly preferred over the other games available during the initial weeks and remained one of the preferred minigames until the second last week, where Wiskin Defense became more popular (see Figure 4-5).

The post-trial questionnaire indicated that all five players agreed that Gekku Race was fun to play, the goal was clear and simple, and it was easy to play. Four of five players agreed that it was challenging and physically tiring; the fifth player did not find the game challenging, and felt neutral about the game being physically tiring. Figure 4-6 shows the participants’ answers to these Likert scale questions.

Assessing the effectiveness of our guidelines

During the semi-structured interview, several participants expressed their enjoyment of the available game actions with phrases like: “Shooting cashews at the others is fun” and “I liked

Figure 4-6: Likert scale questionnaire for the Gekku Race minigame during the home trial.
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burning people”. These actions were possible thanks to the use of our guideline *remove need for precise positioning and aiming*. Following this guideline, we allowed players in Gekku Race to shoot cashews with a narrow but long range of attack and flames with a short but wide range of attack, both allowing players to score a hit without the need of precisely aiming.

One comment giving evidence of the usefulness of our guideline *simplify level geometry* was “I think [it] is good that you are focused on pedaling forward and not worrying about turning and so wasting energy and I guess that’s good”. We made use of this guideline to make the race track linear and without obstacles, removing the need for steering in curves and dodging obstacles, thus making it easier to play the game. This design decision allowed game strategies where players could leave the game controller to one side and dedicate all their effort to pedaling non-stop.

In Gekku Race, pedaling ability had a big impact on performance in the game. To implement the guideline *balance the game for differing abilities* we introduced a parameter mapping the bike’s cadence to the avatar’s speed that we could set individually for each player. We see evidence of the success of this guideline in the fact that all the players spent a significant amount of time in Gekku Race each week, 82.6 minutes on average, as shown in Figure 4-4. Also, all of the players expressed how much they liked the competition in the game with comments such as: “[Gekku Race] was the most fun and with the most competition”, “[I liked] that if a lot of people came on there would be a lot of competition”, and “I liked the most, the chance to be competitive with everybody else”. None of the players indicated that the game was unbalanced, frustrating or boring with any of their comments.

These results show not only that Gekku Race was playable, fun to play, and engaging over the eight weeks of our study, but also that the use of the guidelines *simplify level geometry, remove need for precise positioning and aiming*, and *balance the game for differing abilities* contributed to making the game playable.
4.6.3 The Dozo Quest minigame

Dozo Quest was tested during our participatory design and evaluation sessions and was modified based on the participants’ feedback. To make Dozo Quest playable, we used four design guidelines: simplify level geometry, simplify level flow, reduce consequences of errors, and limit available actions.

Dozo Quest was released on the fourth day of the second week and was available for the remaining six full weeks of our trial.

Evidence that Dozo Quest was playable for this group of participants is that participants played it for an average of 37 minutes per week (see Figure 4-4), equivalent to one of their recommended five play sessions. All participants were able to play the game. All managed to complete the level, including defeating the “boss” enemy at least twice. One participant defeated the boss more than ten times.

According to the post-study questionnaire, four participants agreed that the game was challenging and easy to play, while the fifth participant was neutral. Similarly, four participants agreed that the game was physically tiring, while the fifth participant disagreed. All agreed that the goal of the game was clear and simple and that they had fun playing it (see Figure 4-7).

![Figure 4-7: Likert Scale questionnaire for the Dozo Quest minigame during the home trial.](image-url)
Chapter 4: Evaluation of Liberi’s Action-oriented Minigames

Assessing the effectiveness of our guidelines

In an early version of Dozo Quest, players had difficulties timing their jumps from a slippery ramp or from one moving platform to the other. Following the guideline *simplify level geometry*, we removed movement from platforms and increased friction in the ramps giving the players more time to time their jumps. Evidence that these strategies were effective for improving playability can be seen in the comments given by the participants during our interview, such as: “Timing my jumps was kind of easy” and “I had to time it [jumps and dashes] really well… I found that fairly easy.”

We also saw evidence that following the guidelines *simplify level flow* and *reduce consequences of errors* allowed players to progress through the whole level reaching the boss room multiple times. When we asked participants what they liked the most in the game, one participant said: “[I like] how you progress to different levels of difficulty with jumps”. Two more said “I liked the boss fight… It was a lot of fun” and “I liked killing the boss”. One player appreciated that there was an alternative path she could follow to reach the boss; precisely, she said “[It is] good that there was an easy path.”

The fact that the players were able to use the jumping/dashing mechanic to navigate the whole level, reach the boss and then defeat it gives credit that our guideline *limit available actions* was effective at allowing playability and also allowed players to have fun playing the game.

4.6.4 The Bobo Ranch minigame

Even though Bobo Ranch had been found easy to play by most of the participants of our participatory design sessions, players had issues playing the game as a group. This game was revised based on our observations during our participatory design and evaluation sessions, where two design guidelines were particularly useful: *remove need for precise positioning and aiming* and *make game state visible.*
Bobo Ranch was available for the last three weeks of our home-based trial. The participants played the game for an average of 14 minutes per week, about 10% of their weekly playtime. The participants expressed their happiness with the game saying: “Bobo Ranch was good”, “It was not complicated to understand”, “It is a great sense of accomplishment to get them all in” and “I took it as a personal challenge”.

In our post-study questionnaire (Figure 4-8), the five participants agreed that the game was challenging and physically tiring; four of five agreed that the goal of the game is clear and simple, it is easy to play, and that they had fun playing the game. The fifth participant did not find the goal of the game clear, simple or easy to play, and felt neutral about its fun. This participant commented during the interview that he did not like this game: “I did not really like this one...it was not very appealing to play... [I] didn't find it interesting”.

Assessing the effectiveness of our guidelines

The main goal of implementing the guideline *remove need for precise positioning and aiming* was to allow players to more easily accomplish their goal of clearing the level. By observing players catch sheep with their lassos and successfully clearing the level, we see that the implementation of the guideline was effective. Players found it easy to capture the sheep and their
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comments focused more on highlighting their experiences while pulling the sheep toward the barn, for example: “I found it tiring pulling the sheep” and “It was a challenge to get [all the sheep]. There were a lot. They even got harder if you caught more than one”.

The main goal of implementing the guideline make game state visible was to improve the visibility of the state of the game to allow better collaboration between players. Implementations of this guideline included a visible rope that shows which sheep each player is pulling and pictures of the players to the borders of the screen showing the direction where other players are located. We believe that the fact that players were able to work together as a group to capture sheep and clear the level is a sign that these implementations were useful. Participants liked the multiplayer cooperative aspect saying “Playing this game with the others adds more fun” and “I think helping people in this game is important.”

4.6.5 The Biri Brawl minigame

Biri Brawl was developed after the participatory design and evaluation sessions and therefore none of the participants had played it before the trial.

Biri Brawl was designed with all our seven design guidelines in mind. As we will see, participants did not find any playability issues in the game, but they did not find the game very appealing.

Biri Brawl was available for all eight weeks of the trial; however, it did not get as much attention as Gekku Race, which was also available from the first week, or Dozo Quest, available since the second week. Participants played Biri Brawl an average of 8.8 minutes per week. It was played the most during the first week, where it was played an average of 53.5 minutes per participant, or 30% of the time, but it lost attention as other games became available (see Figure 4-5).
At the end of the study all five participants agreed that the goal of the game was clear and simple and it was easy to play; however, three participants did not have fun playing the game while the other two were neutral about it. In addition, only one participant agreed that the game was challenging, one was neutral and three disagreed (see Figure 4-9). Four participants also thought that the game was not physically tiring and the fifth participant was neutral.

During our interview, the participants were more explicit about what they did not like in this game, with comments such as: “There was something about this game that was not very appealing to me… I didn’t really understand the point of that game to be honest with you”, “[It] was kind of boring even if there were other players, because there was not very much that we did for winning that game” and “if they added more stuff, that would probably make it more challenging and more fun.” Other comments on the little time the game was played were: “it's just like playing tag… it doesn’t really stay fun for a long time” and “there was not many people who find it interesting so when you wanted to play it was only you playing”, which suggests that the choice of game for a player was influenced by the minigames that the other participants were playing.

Figure 4-9: Biri Brawl Likert scale questionnaire.
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Biri Brawl demonstrates that the use of the guidelines for the design of exergames for youth with CP might guarantee playability of the games, but does not guarantee enjoyable play.

Based on the feedback from our participants, we decided to redesign the game, changing its goal and keeping only its underwater style, look of the avatars and simplicity of the controls. The updated version of the game was used in the second and third home trials, one of which is discussed in Chapter 6.

4.6.6 The Wiskin Defense minigame

Wiskin Defense was built after our participatory design and evaluation sessions, so none of the participants had played it before.

Wiskin Defense was available during the last two weeks of this first home trial and it was received with great enjoyment. Wiskin Defense was played an average of 117.5 minutes per week, for a total of 235.1 minutes per player on average (see Figure 4-3 and Figure 4-4); and it was the most popular game during the last week of the study (see Figure 4-5).

According to the post-study questionnaire (Figure 4-10), all participants found the goal of the game clear and simple; they also found the game physically tiring and had fun playing it. Three

![Wiskin Defense](image)

Figure 4-10: Likert scale questionnaire for Wiskin Defense.
Chapter 4: Evaluation of Liberi’s Action-oriented Minigames

Participants agreed that the game was easy to play, one was neutral and one disagreed. Finally, four participants agreed that the game was challenging while the fifth disagreed.

When interviewed, participants did not mention any playability issues; instead, they commented on what they liked in the game, such as “[I liked] defeating enemies and the whole defense concept. And the weapons that you can change”, “The idea of waves of monsters was good stuff”, ”I honestly think that if the Wiskin Defense was [released] earlier it might have been the best, but because of the timing of the release [Gekku Race was played most]”. Only one player expressed a negative feeling about the long term enjoyment of the game: “We kept playing it until it got boring for me.”

Assessing the effectiveness of our guidelines

In Wiskin Defense, we see a combination of our guidelines contributing to each other to enhance the playability of the game. For example, the simple game level (the level is a rectangular cave without obstacles) and simple level flow (enemies spawn from the left and right wall towards the center) allowed participants to easily identify the state of the game to strategize in group how to contain the incoming enemies. And, the limited set of actions (whack or shoot, depending on the weapon selected) do not require accurate positioning or aiming in order to hit the zombies; if players miss hitting the zombie, they can quickly chase it and try to hit it again, therefore forgiving players for errors.

4.6.7 Exertion levels allowed by Liberi

A bonus finding of this first home-based study was that our game Liberi allowed players to reach and maintain their target heart rate for several minutes every week. Participants accumulated an average of 39.4 minutes over their target heart rate per week (see Figure 4-11), suggesting that our games can be effective for motivating moderately vigorous exercise. The number of minutes over target heart rate was usually higher during the weeks of the study where players played longer (see Figure 4-12).
Even though the average number of minutes over target heart rate achieved by our participants during this study was encouraging, most players found it difficult to achieve the weekly goal recommended in the exercise prescription given. The prescription recommended 90 minutes over target heart during the first four weeks of the intervention, 105 minutes during weeks six and seven, and 120 minutes during the last two weeks (see Appendix B).
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Additional strategies to motivate sustained levels of heart rate over the moderately vigorous target while playing the game might be necessary. Strategies such as the implementation of heart rate-based rewards, identification and redesign of areas in the minigames that allow players to rest or require slow pedaling, and reduction of the time players spend traveling around the island have been considered. The heart rate-based rewards have already been implemented in a newer version of Liberi. The other strategies are a work in progress.

4.7 Summary

Through this first home-based study we have shown that despite the recommendations of traditional guidelines for the design of games for people with motor disabilities, it is possible to create action-oriented exergames that can be played and enjoyed by youth with CP at GMFCS level III. We demonstrated this by showing how a novel set of design guidelines derived from a participatory design process with youth with CP could be used to implement fast-paced exergames that youth with CP can play and enjoy.

We showed that the games built during our participatory design process and the ones built at our lab making use of our design guidelines were all playable during an eight-week home-based trial for at least this group of five youths with CP.

We analyzed how the implementations of each of the guidelines in the minigames contributed to the gameplay accessibility in each minigame. For example, in Dozo Quest, our decision to make platforms in the level static and to add friction to ramps was an implementation of the guideline *simplify the level geometry*. We showed that this implementation removed issues with progression through the level identified during our participatory design sessions, and allowed participants of our home-based trial to progress through the whole level until they reached and defeated the final boss.
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We also found that all the minigames, except the game Biri Brawl, were highly enjoyed. It is worth noting that the use of the guidelines for the design of exergames for youth with CP focuses on providing playability for this population, but it does not guarantee the enjoyment of the resulting games. Other factors such as the game goal, game style, and gaming preferences of the players can affect the enjoyment of the games. A useful strategy to achieve games that are enjoyable is the involvement of the target population in the design process of the games. We did this for three of our minigames. Two of them were found fun by all the participants and the third was found fun by four out of five participants while the fifth was neutral.

As a bonus finding we also saw that our game Liberi in general has promise as an effective way of motivating youth with CP to perform moderately vigorous exercise.

The following chapter focuses on the challenges of designing for social accessibility in video games for youth with CP.
Chapter 5

Design for Social Accessibility

This chapter reviews the challenges of designing online games that youth with CP can use to socialize with others. We present our approach to overcoming this challenge introducing a novel set of guidelines for providing social accessibility in online games for youth with CP and illustrate how we implemented these guidelines in the context of our game Liberi. An evaluation of the resulting game in terms of its effectiveness for allowing and promoting social interaction is presented in chapter 6.

5.1 Introduction

Participation in social activities provides avenues for forming friendships and developing concept of self, and for youth, social participation allows the development of life skills and fulfillment of adult roles [55]. As discussed in chapter 2, youth with CP have decreased opportunities to participate in social activities with peers, in part due to special needs in transportation, accessible facilities, and coordination of assistive services [55].

Online video games represent a promising approach to allow youth with CP to socially communicate and interact with peers from the comfort of their homes. Video games can provide a common activity for players, forming a basis for social interaction. In networked games, players may compete against other human contestants, work cooperatively to achieve a common goal, or simply get together with others to chat [28].

But the social benefits of commercial online video games may not be available to youth with significant motor disabilities such as those associated with CP. Youth with CP have limitations in physical abilities that are usually required to play in groups effectively. In addition, even within
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Commercial networked games, there can be unintended barriers to group play that can be significantly difficult to overcome for this population [28].

As we showed in chapter 3, fast-paced video games that are typically popular among young people need to be designed specifically around the abilities of people with CP. To guarantee that the social benefits of online gaming are accessible for youth with CP, online games also need to be specifically designed around the abilities of this population. Since most of the interactions with the game and the other players happen in a virtual world, the computer can mediate these interactions, reducing the challenges of having a physical disability. Indeed, the virtual world can offer novel experiences that individuals with physical disabilities are not able to realize in “real-life” [121].

In this chapter, we discuss how a networked game should be designed to allow and enhance social play among people with physical disabilities such as those associated with CP. We present our approach to overcoming this design challenge in the context of our game Liberi. Liberi illustrates three guidelines for the design of games supporting social interaction among people with motor disabilities:

- **Frictionless group formation:** It should be easy for players to join up with others for play sessions within the virtual world.

- **Dynamic balancing for player ability:** People of different physical ability levels should be able to play together.

- **Varied play styles:** The game should offer a wide range of game styles to support different preferences and abilities.

To determine how effective Liberi can be in practice in promoting social engagement, we evaluated Liberi through a ten-week home-based study where a group of youth with CP played the game online from home. In this study, we analyzed the social interactions between players.
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and the way they used the features of Liberi that allowed group play. This study and its results are discussed in detail in chapter 6.

The following sections of this chapter discuss the challenges of and approaches to designing online games that are an effective venue for social interaction among youth with CP. First we review barriers to group play in existing games and how they might be particularly challenging for youth with CP. Next we discuss strategies that attempt to deal with some of these barriers. We then describe the design guidelines underlying the design of Liberi as a platform for social interaction of youth with CP and present specific examples that illustrate how we implemented each of the guidelines in Liberi. We conclude this chapter by presenting a summary of our guidelines and the specific examples that illustrate how we implemented them.

5.2 Challenges and approaches

In chapter 3, we described a year-long participatory design process with youth with CP where we identified physical limitations typical of this population that prevent them from playing fast-paced videogames. These limitations affect manual ability, hand-eye coordination, visual-spatial reasoning, gross motor function and motor habituation. These abilities are usually required to play effectively in groups, and therefore, limitations in these abilities might prevent youth with CP from enjoying the social benefits of online games. With these limitations in mind, we observed that commercial networked games can introduce unintended barriers to group play that might be significantly difficult to overcome for people with motor disabilities such as those associated with CP. Some of these barriers can partially explain that even big commercial networked games can be played with surprisingly little social interaction – for example, players of World of Warcraft can spend as little as 25%-30% of their time playing with others [4]. We have grouped these potential barriers in two main categories: difficulties establishing player groups, and difficulties associated with differences in players’ abilities. We now review these obstacles and discuss how they may be particularly pronounced for people with CP.
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5.2.1 Establishing player groups

Players may have difficulty meeting others within a virtual world. Players may be spread over a large virtual geography, requiring them to travel for a long time before being able to group for a shared activity [28]. Once players have arrived in the same location, they must formally band together as a group. This typically requires them to use a cluttered graphical user interface (GUI) to specify the group’s membership and parameters. For example, World of Warcraft offers multiple servers to which players can connect depending on their gaming preferences. Other networked games offer multiple gestures to start or carry out social interactions through commands assigned to combinations of keys or buttons clustered in a complex user interface [27]. This task requires manipulating small objects such as buttons on a game controller or a keyboard, presenting difficulties for people with limited manual ability [19, 5].

Additionally, over 83% of youth with CP present seriously affected visual-spatial processing abilities [60]. This can make it difficult to effectively navigate virtual worlds based on complex visual cues or to successfully find places or persons.

5.2.2 Differences in players’ abilities

Players of commercial networked games can be hesitant to admit new players to their group. Guilds in World of Warcraft, for example, can be highly exclusive, only admitting players at similar levels of experience [28]. One explanation for this exclusivity is that advanced players may see no benefit in cooperating with lower level players [28]. This segmentation of the players and difficulty breaking into existing groups can interfere with social interaction.

In many games, playing in groups requires strong manual ability and visual motor integration, both limited in youth with CP. Competitive and cooperative social interactions in multiplayer games can require players to quickly perform actions to effectively defend or attack during a competition or a group battle. Limitations in manual ability of youth with CP can make it difficult to use common control schemes that involve pressing different buttons in rapid succession, using
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multiple buttons at the same time, or selecting a specific button at exactly the right time. Additionally, youth with CP have lower performance in visual-motor integration tasks than youth without CP. Even though eye responses in youth with CP can be as fast as in youth without CP, hand movements are slower and less efficient [92], making it difficult for them to quickly react to time sensitive game events. These difficulties limit the way youth with CP react during online competitions with others or the way they contribute to group battles.

5.2.3 Possible solutions

In chapter 2, we described strategies used in commercial networked games to encourage people to group. These strategies include offering different in-game roles for the players to choose from [27,28], steering players towards social gathering points in the virtual world [26], giving players down-time in the game to be social with others [58], allowing players to show off their achievements [13,28], implementing social gestures for avatars [27], and providing matchmaking tools. These solutions may help foster social interaction, but even successful games implementing these solutions have been inconsistent at cultivating group play.

Traditional guidelines for the design of accessible gameplay or even the guidelines for the design of exergames for youth with CP introduced in chapter 3 do not necessarily address these barriers to social play. The existing literature shows promise for networked games to foster social interaction among youth with motor disabilities such as CP; however, there is to date no information on how to approach this game design challenge.

In the following section, we describe how we addressed this challenge in the context of our game Liberi.

5.3 Design of Liberi as a platform for social interaction

Liberi has been designed with the goal of not only providing an alternative to physical activity for youth with CP but also providing this youth with a venue for social. The game takes place in a
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persistent world that allows a small group of players to meet up and play together. A central plaza gives access to six minigames and various shops where players can purchase avatar upgrades, costumes and weapons that allow them to configure the appearance and abilities of their avatars in the game. Figure 3-7 shows three players congregating around the shops in Liberi’s central plaza. The minigames embody a range of collaborative and competitive gameplay styles, and can be played in groups or “solo” with artificial intelligence “bots”. Liberi provides a voice chat system that allows players to invite each other to the different minigames, coordinate cooperative play, cheer or playfully gibe each other, or simply chat.

To support social interaction in Liberi, we followed three high-level design guidelines: support frictionless group formation, so that players can easily get together in a play session; balance for player ability, so that players of differing physical abilities can easily play together; and support a variety of play styles, to engage players of different physical abilities and preferences. We now review in detail how the game was designed to address these goals.

5.4 Designing for frictionless group formation

As discussed earlier, players of online games often spend little time playing with others. One of the barriers to group play is the difficulty in forming groups: in finding others to play with, and in navigating complicated interfaces to form an in-game group. We designed Liberi to minimize these difficulties. Specific design decisions included automatic establishment of voice communication, short travel times within the virtual world, on-screen presence indicators, automatic grouping, and easily joinable activities.

5.4.1 Automatic voice communication

Most networked games support voice communication between groups of players. In most games, communication is started manually, with a user interface that allows the specification of who will take part in the voice session. A barrier to grouping is derived from the fact that some players are
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able to talk by voice and others who are not in the session cannot. In Liberi, all players are equipped with a headset and are automatically placed in the same voice channel as soon as they log in. The immediate establishment of a voice link to other players makes it easy to determine which other players are in the game, and to negotiate a group activity.

The decision to include all players in a global voice chat has the disadvantage of limiting the number of players in the game; we have found that up to eight players work well in a voice chat.

5.4.2 Short travel times

One of the major barriers to grouping in virtual world games can be the size of the world and the time required to travel across it. Liberi has a varied virtual world in which players can travel between zones as varied as jungle, desert, space, an ice cave and a lake. However, Liberi was designed to allow players to congregate quickly to allow them to play together, with a goal that players can travel to any other zone within one minute. Figure 5-1 shows a map of the different regions of Liberi that give access to the different mini games. Here we can see that all the regions

![Figure 5-1: Map of the different regions giving access to the minigames in Liberi.](image)
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can be easily accessed through portals and short distance travel. In our tests, we found that the longest trip in the virtual world (from the region depicted at the bottom left of the map to the region shown at the bottom right) could be completed in 45 seconds.

5.4.3 On-screen presence indicators

One of the most basic challenges in forming a group is locating other players within the virtual world. To supplement voice chat as a way of locating others, we provided visual presence indicators in the form of avatar “stickers”. These consist of miniature pictures of the other players that appear on the borders of the screen. The stickers are positioned to indicate the direction in which the other players can be found. Figure 5-2 shows two stickers indicating that there is a player out of view to the east, and another player reachable through the portal on the left.

5.4.4 Automatic grouping

In Liberi, unlike traditional online games, players do not perform an explicit action to specify which other players they wish to play with. To enter a minigame, players stand on a launch pad. When one of the players presses the action button on their game controller, all the players standing on the launch pad are taken into the minigame. This action implicitly forms a group for the purpose of playing that game; there is no process of requesting or granting access to a group.

![Figure 5-2: Launch pad, portal and players’ stickers.](image-url)
or of specifying group membership. Players need only stand on the launch pad and press the button. Figure 5-2 shows a player (on the right) using the launch pad to enter the Dozo Quest minigame.

5.4.5 Easily joinable activities
In many online games, once the game has started, it can be difficult for others to join. As discussed, in Liberi, players can join an ongoing minigame by standing on its launch pad and pressing the action button. The minigames are designed to accommodate late-comers. For example, in the Pogi Pong team-based hockey-style game, new players are assigned to the team which currently has fewer players. In the Wiskin Defence minigame, the new player joins the group of defending players, and the game difficulty increases to account for the additional player's firepower.

5.5 Balancing for player ability
In chapter 3 we described the design guidelines used to ensure that Liberi was accessible for players with GMFCS level III CP. Despite using these guidelines, the physical abilities of individuals within the GMFCS level III classification can vary a great deal, potentially causing players to only stick with games where their abilities allow them to perform well. Therefore, it was important to ensure that all the minigames allow people with different abilities to play together to avoid social exclusion based on an inability to play with others.

5.5.1 Balance for ability level
Liberi’s minigames were designed to allow people of differing ability to play together, in order to avoid segregating players based on skill, limiting opportunities for social interaction. In Liberi, players move by pedaling a bicycle. To eliminate differences in avatar speed due to differing gross motor function, all avatars move at the same speed rather than mapping a higher pedaling cadence to faster avatar movements. Keeping all avatars at the same speed helps to shrink the
disparity in the outcomes of minigames where pedaling speed is important, such as the Gekku Race racing game, or the new Biri Brawl fighting game. Another benefit of having players’ avatars move at the same speeds is that as players travel around the island it is easy for them to move as a group.

5.5.2 Group goals instead of individual goals

It can be difficult for players with differing abilities to play in a group because players with lower skill can feel a sense of defeat if their ability to win or to contribute to the team is much lower than their group mates; conversely, players with stronger skills may become frustrated if another player is not keeping up. Several of the games in Liberi adopted a single group goal in order to mask differences in ability. For example, in the Bobo Ranch round up game, players work as a team to move sheep to a barn. When this goal is completed, all of the players receive the same reward for completing the objective. By hiding differences in ability, we eliminate a source of friction between players.

5.6 Supporting a variety of play styles

Liberi was designed to support a variety of play styles, with the goal of satisfying individual preferences and differences in physical ability. The minigames include competitive, collaborative and team-based styles. One of Hanarra’s Laws describes how over time players who stick with a game will be those who enjoy the style of the game offered [58]. By providing a variety of play styles, we can satisfy individual players’ personal preferences. Additionally, the controller inputs for each minigame requires different fine motor skills, helping players with differing manual abilities to find a game they are all able to play. Games can also be played solo, where computer controlled “bots” fill in other player slots.

There are six minigames in total, ranging over a single player/cooperative platform game, a competitive racing game, a cooperative zombie defense game, a team-based space hockey game,
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a brawler fighting game and a cooperative round-up game. In chapter 3, we described three of these minigames from the perspective of their playability. Now, from the perspective of their social aspects, we describe in detail three minigames of different styles, and we briefly describe the social aspects of the remaining three.

5.6.1 Wiskin Defence

In Wiskin Defence (Figure 5-3), the wiskins are cute penguin-like creatures sitting in a nest in the centre of the game arena. Zombies of varying types emerge from the sides of the arena and travel inward. If a zombie reaches the nest, a wiskin is eliminated. The job of the players is to defend the wiskins by killing the zombies before they can reach the centre. Players choose, purchase, and upgrade weapons to use in this game at one of the shops in the central plaza.

Social aspects: Since different weapons vary in effectiveness against the different types of zombies, success is far more likely when players coordinate their movements and attacks to keep the monsters at bay. This cooperation mainly manifests in two ways. Most commonly, players will simply ask for help from others when they are being overwhelmed. Alternatively, a player can take a commanding role and direct the movements of others, coordinating the overall defense of the wiskins. Another form of social interaction stems from discussion about the effectiveness

![Figure 5-3: Three players play Wiskin Defence.](image-url)
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of personal preferences for different types of weapons, allowing players to learn more about weapons they haven’t used.

5.6.2 Gekku Race
In Gekku Race (explained deeper in section 3.5.4), players are “gekku” lizards racing to be the first to reach the top of a wall. Gekkus can slow their opponents either by spitting cashews or by breathing fire. Once one gekku reaches the top, the game ends, and all of the gekkus slide back to their starting position for another round.

Social aspects: Gekku Race is a competitive racing game that allows players’ avatars to directly interact through breathing fire and spitting cashews. This encourages social interaction by allowing players to react to others’ actions towards them. A good dodge or well-timed hit can provoke verbal interactions between players. Players can gibe or cheer each other on during the game. Outside the game, players can discuss strategies of when to attack others, which attacks they like best and recall interesting interactions between their avatars during gameplay. The racetrack is short, requiring about 45 seconds to complete, allowing players to join in an ongoing competition and/or wait shortly for the race to restart.

5.6.3 Dozo Quest
In Dozo Quest (Figure 5-4) (explained deeper in section 3.5.2), players maneuver a spiky ball by rolling and dashing through a desert maze. Within the maze lie a variety of enemies, obstacles, traps and loot. Players can choose to jump over enemies or attack them. At the end of the game, players must defeat a powerful boss either alone or in a group (see Figure 3-9).

Social aspects: Dozo Quest can be played as a single-player or group game. A group of players can traverse the maze together, collecting loot and killing enemies along the way. Barriers increase in strength when more players join, making it difficult to reach a new section without working together. Once players reach the end of the game, they are faced with a large “boss”
fight. The large boss (Muferoth) also increases in strength based on the number of players that are in the game. The increase in difficulty encourages players to discuss how best to attack and defeat Muferoth. This is an example of a dynamic difficulty adjustment algorithm, used to balance minigames for varying numbers of players.

A key aspect of Dozo Quest that encourages group interaction is that players can join in at any time. A new player is placed at the beginning of the maze and can catch up to the others. Being able to join an existing game at any time removes the need for players to wait for others to finish the game, making it easy for an individual to join the group.

5.6.4 Other minigames

*Bobo Ranch* (explained in detail in section 3.5.3) is a co-operative round up game where players are tasked with lassoing and dragging rebel bobos (flying sheep) back home to their barn. The game ends when all bobos are home. Players can lasso multiple bobos at a time. Bobos are easier to move and produce more bounty when lassoed by multiple players at once, encouraging cooperative play.

The revised *Biri Brawl* is a competitive brawl fighting game in an underwater arena. Players control a jellyfish with a fist inside it, called a biri, and punch out other biris until their health
runs out to accumulate points. A defeated biri can join the battle again with full health after a short time. Figure 5-5 depicts a players’ biri in the middle of the screen about to meet another biri coming from the upper-left corner.

In *Pogi Pong*, players take the form of space hedgehogs. Players are split into two teams competing to knock a star into the opposing team’s goal. The team that scores the most goals wins. Pogi Pong encourages cooperation between team members and competition with the members of the opposing team. Figure 5-6 shows a match in Pogi Pong where two members of the red team control the star.
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5.7 Conclusion

In this chapter we have shown how existing online games may present unintended barriers to group play that are particularly difficult to overcome for people with motor disabilities such as those associated with CP. In particular, we showed how people with motor disabilities might find it difficult to establish player groups and to play with others who have different abilities.

Through a year-long participatory design process we identified the abilities of youth with CP and specified a novel set of guidelines for the design of games that youth with CP can use to effectively socialize. We gave examples of how each guideline was implemented in the context of our game Liberi.

In summary, the guidelines and specific examples of their implementation used when designing Liberi as a platform for social interaction of youth with CP are described below.

1. *Design for frictionless group formation:* It should be easy for players to join up with others for play sessions within the virtual world. For this guideline we used the following strategies:
   - Allow automatic grouping of players,
   - Automatically establish a voice chat among all players,
   - Provide clear on-screen indicators of the players presence,
   - Make game activities easily joinable, and
   - Avoid virtual world designs that require long travel times.

2. *Balance for player ability:* People of different physical ability levels should be able to play together. We illustrate this guideline with the following strategies:
   - Balance the mapping of player abilities to movement in the game, and
   - Provide a common group goal to mask the differences in players’ abilities.

3. *Support a variety of play styles:* We implemented this guideline by providing enough games to support individual preferences as well as differences in ability.
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Table 2 offers an alternative view of our guidelines and how they have been implemented.

Table 2: Examples of the implementation of our design guidelines for social accessibility.

<table>
<thead>
<tr>
<th>Guideline</th>
<th>Example 1</th>
<th>Example 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design for frictionless group formation</td>
<td>In Liberi, there is no process for requesting or granting access to a group or for specifying group membership in order to play a minigame in groups. Players need only stand on a minigame’s launch pad and press the action button. This action implicitly forms a group for the purpose of playing that minigame.</td>
<td>Players can congregate quickly in the virtual world to allow them to play together. Players can travel to any other zone within one minute.</td>
</tr>
<tr>
<td>Balance for player ability</td>
<td>To eliminate differences in avatar speed due to differing gross motor function, all avatars move at the same speed rather than mapping a higher pedaling cadence to faster avatar movements. This helps shrink the disparity in the outcomes of minigames where pedaling is important, and makes it easier for players to travel around the island as a group.</td>
<td>Several minigames provided a single group goal in order to mask differences in players’ ability. In Bobo Ranch, for example, players work together to move the sheep to the barn. Once the goal is completed, all the players receive the same reward.</td>
</tr>
<tr>
<td>Support a variety of play styles</td>
<td>Gekku Race is a competitive minigame where players can decide whether they want to put all their efforts into pedaling or to combine pedaling and shooting items at the others to win the race.</td>
<td>The Wiskin Defense minigame features cooperative gameplay, allowing players to coordinate their defense against a horde of zombies using short-range and long-range weapons.</td>
</tr>
</tbody>
</table>

In the following chapter we present the design and results of a ten-week home-based study with youth with CP where we evaluated Liberi, the resulting game where we used these guidelines, as a venue for social interaction. As we will see, Liberi allowed strong social interaction among youth with CP.
Chapter 6

Evaluation of Liberi as a Platform for Social Interaction

To evaluate the design principles underlying Liberi as a social platform for youth with CP, we conducted a ten-week trial where ten participants with CP played the game from home. In chapter 4 we reported the evaluation of the game through an earlier home based study in terms of its playability and fun; in this chapter, we report the results of a larger study where we focused on the effectiveness of the game in fostering social interaction.

6.1 Evaluation of Liberi as a platform for social interaction of youth with CP

For this new evaluation of Liberi, we performed a prospective case study where a group of ten participants played Liberi from home over ten weeks. We had only eight exergaming bikes available, and therefore participants were split in two consecutive cohorts of six and four players. Both groups played the same version of Liberi and its minigames: Gekku Race, Dozo Quest, Wiskin Defense, Bobo Ranch, Biri Brawl and Pogi Pong.

6.2 Participants

We recruited ten participants, four of whom had participated in our initial participatory design and evaluation sessions. Three participants were female and seven were male. The mean age was 15.2, ranging from 12 to 18. Seven had spastic diplegia (lower limbs are affected) and three had spastic triplegia (lower limbs and one arm are affected). Nine were at GMFCS level III (require a mobility aid like a walker or wheelchair), and one was at GMFCS level IV (requires a powered wheelchair). All participants were able to communicate verbally without problems. Two out of six participants from the first group and all four participants from the second group had existing social connections through attendance in sporting groups such as sledge hockey and basketball.
Seven participants said they had experience with commercial game consoles such as Nintendo Wii, PlayStation 3 and Xbox 360.

### 6.3 Study setup

Before the beginning of the study, the exercise prescription used during our first home-based trial was adjusted to cover ten weeks of intervention based on the recommendations of Dr. Darren Warburton and Dr. Darcy Fehlings. The updated prescription recommended playing at least three times a week, summing to at least 60 minutes over the target heart rate during the first two weeks, 75 minutes during weeks three and four, and 90 minutes during the last six weeks. Following safety recommendations given by Dr. Darcy Fehlings, the prescription included a limit for play time of 40 minutes over their target heart rate or a total of 60 minutes of play per day, and five additional minutes were added as a mandatory warm-up before the session and five more for a cool-down after the session. The new prescription can be found in Appendix C. The game was instrumented to display a warning signal to participants that exceeded a heart rate level over the resting heart rate plus 60% of heart rate reserve.

All participants attended a preparatory session at the hospital. The goals of this session were:

- To instruct the participants on the basic mechanics of the game and to let them play two of the minigames. A group of research assistants from the hospital and from the EQUIS Lab attended this session.
- To determine a proper resistance of the bike for each participant so that they were able to pedal unassisted while providing enough challenge to encourage moderate levels of exertion, and to measure the participants’ resting heart rate to calculate the new target heart rate to follow the exercise prescription. This procedures were conducted under the supervision of Dr. Darcy Fehlings at HBKRH.

A research assistant and I then set up an exergaming station in the home of each participant. The station featured a custom-designed recumbent bike [46], a 23” screen all-in-one computer
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running the Liberi game, a wireless game controller, a wireless headset and a wireless heart rate monitor. Due to limited numbers of these special-purpose stations, participants were divided into two successive cohorts, one with six participants and one with four. The game server was open six days a week for a 1.5 hour session. By opening the server for 1.5 hours instead of 24 hours a day, we intended to increase the opportunity for the participants to meet others online. Participants were free to determine when (and whether) they wanted to play within these periods; however, they were encouraged to follow the exercise prescription given.

A private Facebook group for the study was created. Seven of the ten participants joined the group. Research assistants used the group to post video tutorials of upcoming minigames. Participants were encouraged to use the group to set up days to meet online and play together.

To keep the novelty of the minigames high, we introduced them progressively, starting with Gekku Race and Dozo Quest, and adding a new minigame every two weeks. The order was: Biri Brawl, Wiskin Defence, Pogi Pong, and Bobo Ranch.

6.4 Data

The game created log files for participants as they joined the server. For each second they played, the game recorded the time, the minigame or shop the participant was in, any in-game events, how many others were in that minigame, and input from the game controller. This data allowed us to extract information about what minigames participants played and who they played with.

A “game monitor” research assistant observed each game session during the trial using an administrator tool that showed the locations and activities of the participants’ avatars. The game monitors were included in the open voice communication channel and were instructed to only interact with the participants in case of technical issues or inappropriate behavior. After each session, the game monitor wrote a report to record activities and interactions between
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participants. The monitors produced 119 reports, 6 per week over 20 weeks, minus one statutory holiday.

A health sciences graduate research assistant from HBKRH was assigned the role of coach for participants of the study. The role of the coach was to call the participants every week to inform them how they were reaching the goals of the exercise prescription and to encourage them to try their best to accomplish them. The coach provided a written report following each call. In total, 38 calls were performed and reported, as subject to coach and participant availability. These calls were mainly focused on the participants’ adherence to the exercise prescription, and therefore contributed little to the analysis of the social aspects of using the game, which is the focus of this chapter.

At the end of the study, participants completed a custom-designed Likert-scale questionnaire focused on their experience with each minigame followed by a short semi-structured interview. The questionnaire and interview can be found in Appendix C.

6.5 Results

To analyze the data collected over the ten weeks of this study, I received significant assistance from Mallory Ketcheson and Adrian Schneider, master students at the EQUIS Lab. Both helped organizing and filtering information from the game logs, the game monitor reports and the Facebook group.

We found that Liberi met its design goals of enabling social interaction among youth with CP, while providing low barriers to forming and playing in groups. We provide evidence based on data collected from the questionnaires, interviews, game session reports and the Facebook group, as well as quantitative information extracted from the log files recorded by the game. As we will see, this data indicates that, at least for this collection of participants, Liberi was a highly effective platform for fostering social interaction. This allows us to conclude that when games are
designed correctly, networked gaming has great potential as a social outlet for people with motor disabilities.

We begin by giving a high level overview of the degree to which participants chose to interact socially and the forms that this interaction took. We then tie these observations to an analysis of the effectiveness of our three design principles of frictionless group formation, balancing for ability, and supporting a variety of play styles.

### 6.5.1 Social interaction fostered by Liberi

Liberi successfully provided a platform for social interaction that inspired high engagement among participants. On average, each participant played a total of 1,659 minutes over the ten weeks (SD: 609), or an average of 2¾ hours/week. Participants played with others 69% of the time that other people were online. Figure 6-1 shows that all participants spent the majority of time playing with others when at least one other person was available to play with. The 31% of the time played alone includes time travelling within the virtual world to meet others, time spent shopping, and solo play of minigames.

![Figure 6-1: Percentage of time players chose to play with others.](image)

All players chose to play with others the majority of the time they could (average: 69% of the time).
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The large percentage of time that players chose to spend with each other indicates that they valued group interaction. This high participation in group play also suggests that our design decisions regarding frictionless group formation and balancing for player ability were effective.

Participants’ preference for group play is shown by differences in the length of daily gaming sessions when there were others online versus when participants were alone. We ran a two-sample t-test assuming unequal variances comparing participants’ session length when online with others (Mean: 50.2, SD: 19.8) versus when they were alone (Mean: 37.1, SD: 19.4) and found that players stayed online longer when other players were online with them (t(62) = 10.87, p < 0.01). On average, sessions were approximately 13 minutes longer when players were able to play with others (Figure 6-2).

Game session reports describe players joining the server and, if others were not online, leaving the game soon after. This behavior suggests players were largely interested in playing the game together. A weekly coaching call report recounts a discussion with a participant: “P10 said that Friday’s session went well and that the only reason he left 20 minutes into the session is because no one else was on.” To avoid playing alone, players would often use the voice chat to arrange times to meet online and play together in future sessions. One game session report explains:

![Figure 6-2: Average session length for participants when alone and with others.](image-url)
“When P5 had to leave, they decided to plan their next meeting on Facebook.”

We also received an encouraging response from one of the participants’ parents that highlights the social facet of the gaming experience for the participants and their families. One month after the study finished, we received an email from the participant’s father highlighting the physical, social and entertainment benefits his son experienced during the study. He hoped to reach out to the other participants and their parents to create a community in which the youths with disabilities could continue socializing and playing networked games together.

Players used voice chat to coordinate their activities within the game, including deciding what minigame to play, discussing strategy, and explaining gameplay. A game session report gives a typical example of such interaction: “When P9 came on, P10 asked him to play Wiskin Defense. P9 agreed. While P10 was waiting for P9 [to finish his warm-up] he played some Gekku Race. When they were playing Wiskin Defense, P10 told P9 to buy ice gems to complement his fire gems. P10 vocally coordinate[d] P9’s and his own movements to clear the fire and ice resistant zombies. After a few games, P10 suggested that they try the newly released game, Pogi Pong. Since P9 had not played Pogi Pong before, P10 offered to explain the rules of the game.”

Social exchanges extended beyond gameplay. For example, one game session report states: “In between games of Wiskin Defense, these two participants talked about their mutual friends, the weather and school.” Players took advantage of the option to communicate via headsets from anywhere in Liberi and at times would continue socializing using the headsets even when playing different minigames. One monitor reported: “P1 wanted to play Wiskin Defence and P3 wanted to play Dozo Quest again. So they ended up separating but they did not stop talking. P1 was talking about strategies to beat the game and P3 participated in the conversation too. P3 got intrigued and wanted to play Wiskin Defence with P1. Although they did not get very far, they had a lot of fun!” The experience of hearing players in other minigames talking and having fun brought P3 and P1 together in the minigame where they could virtually interact.
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One repeated form of social interaction was that some players took on the role of a coach. One excerpt from a game session report describes: “P2 taught P1 how to buy and place the dragon egg, and P1 taught P3 how to do the same. Although P3 did not pick up the instructions right away, P1 was patient to teach P3 again until she finally understood.” This coaching behavior was not always welcome; from another report: “P1 is most active with his microphone and takes the ‘team captain’ role and orders P7 and P9 around. I can tell P7 and P9 get annoyed by P1 sometimes and they simply don’t listen to him. However, with each passing wave, they get more excited and I believe P1 plays a huge role as a morale booster.”

We were interested in whether players grouped in an inclusive way, or tended to form exclusive collections of friends who preferred to play together. Player log data showed that participants played with whoever was online, rather than forming cliques. Figure 6-3 presents the number of minutes the players in both groups spent playing with the other participants in the study. Participants played with all other participants. Game monitors did not see incidences of exclusion of players.

Seven of the ten participants possessed Facebook accounts and were therefore able to participate in the study’s Facebook group. All seven stated that this group was helpful for communicating with the other players. All seven considered it useful for arranging times to play together, with five of the seven saying it was as valuable as or more valuable than communication during the game sessions themselves. Five of the seven directly stated that access to the group encouraged them to play. The two cohorts used the Facebook group differently. In the first cohort, only two participants posted to the group a few times and “liked” and replied to each other comments and our game updates posts. A third participant “liked” a few of our game updates posts. Nevertheless, the four first-group participants with accounts reported Facebook as being useful. The game session reports show that players of this group would often agree to coordinate play sessions through Facebook. Participants might also have used Facebook to communicate in
ways we could not see, likely through direct messaging. In contrast, the second cohort made extensive use of the Facebook group by posting to the group’s “wall” itself. For example, one of the participants posted a picture on the Facebook group showing how close he was to reaching 9,999 coins in the game. These observations led us to conclude that social media in the game is useful in coordinating game meeting times and that its use can differ greatly depending on the people involved.

To summarize, we saw strong engagement from participants in the game. Participants preferred to play with others, as evidenced by their playing together when possible and playing...
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longer sessions when with others. There is evidence that a component of this preference was the social interaction afforded by group play, as seen by players’ engagement in discussions beyond the gaming context, the social interaction even when not playing together, the adoption of the coaching role, and the contact from a parent highlighting the positive social interaction in the study.

6.5.2 Frictionless group formation

As we discussed in chapter 5, virtual world games often have structural barriers to forming groups with other players, and these barriers have the potential to be particularly severe for people with motor disabilities. As we have seen, participants played with others most of the time that it was possible. This indicates that the mechanisms for finding others to play with and for establishing groups were effective. The design decisions that were most important in this were automatic voice communication, on-screen presence indicators and automatic grouping. We now describe these, discussing how we observed them in our study.

Automatic voice communication

Participants used voice communication frequently to locate each other in the virtual world. One game session report mentions that: “Sometimes the players will want to join a game together, but are all sort of heading in random directions, so they'll stop and coordinate.”

A second common use of voice chat was to negotiate what game to play when participants wanted to play different games. The voice chat allowed players to communicate their preferences. An example from one game session report stated: “P4 asked P5 and P3 what game they wanted to play together. After a few seconds of discussion, they decided to play Wiskin Defense.”

On-screen presence indicators

While the effectiveness of the on-screen presence indicators of Figure 5-2 was not formally tested, there are indications that they helped participants find others to play with. For example, during a technical outage of the voice chat tool, players were able to find each other despite not
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being able to speak; the players must have been able to follow the avatar “stickers” to locate each other.

**Automatic grouping**
The high frequency with which participants grouped when others were available to play indicates that the automatic grouping feature was effective.

Interestingly, the ease of forming groups led players to treat them fluidly. We frequently saw players disband from the group, play something else for a while, and then re-join the minigame they had left in progress. The reason reported by game monitors for this behaviour was often that players wanted to play different minigames but still wanted to retain contact with the others. The following excerpt from a game session report highlights the ease with which players were able to change the group formations throughout a single session: “As time passed, P1 wanted to play Wiskin Defense and P3 wanted to play Dozo Quest again. So they ended up separating but they did not stop talking.”

6.5.3 Balancing for ability
We found that players experienced few difficulties in group play despite significant differences in physical abilities. Evidence of this is that all the players played with at least one more player the majority of the time when others were available (as was shown in Figure 6-3). We now highlight two interesting features of group play with significant consequences to game designers: first, that players exhibited a preference toward cooperative play as a way of reducing the impact of different ability levels, and second, that our use of dynamic difficulty algorithms negatively impacted accessibility.

**Cooperative play**
Several of Liberi’s minigames allow cooperative gameplay, where the group has a common goal. As discussed in section 3.2, cooperative games help balance for players of different ability by allowing them to contribute towards the group’s goal at whatever level they are capable of. For
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example, in Wiskin Defense, the players defend the wiskins from zombie invaders as a group; in Dozo Quest, players defeat the enemy “Muferoth” as a group. When well designed, in a cooperative game, it is not obvious which members of the group contributed most to the game’s goal.

As evidence that this approach was successful, participants expressed a strong preference for cooperative group play versus competitive or solo play. During the interviews, when asked whether they preferred to play competitively with others, cooperatively with others, or alone, seven specified cooperative play, two specified competitive play, and one did not provide a clear preference. The game logs support this stated preference; Figure 6-4 shows that the cooperative Wiskin Defense minigame was the most played by groups (and also the most popular overall.) As an example, the game monitors reported that Wiskin Defense was particularly difficult for P3 (she was our participants at GMFCS level IV, and she had difficulty hitting the zombies). But she enjoyed playing it when others were online because she was able to interact with the other players.

![Figure 6-4: Preferred minigames based on number of players online.](image)
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while they held the zombies back. Here, the inability of P3 to contribute to the game was masked by the contributions of the others.

An interesting behavior was observed in the competitive Biri Brawl minigame. Biri Brawl is designed as a brawling game where all players fight for themselves. Computer-controlled “bots” are added in as more enemies. In one session, instead of playing competitively, the players created an alliance and teamed up on the biri bots. Again, this compensated for the difficulties that one participant experienced playing the game. A monitor reported: “P3 said that ‘it was intense,’ and it looked like she was having a lot of fun even though she was not excellent at the game.”

**Challenges with dynamic difficulty adjustment**

Since players are able to easily join and leave minigames, it was important that the difficulty of the minigames be dynamically adjusted for a varying number of players. To accomplish this goal, Liberi uses an adaptive balancing method where the minigames become more difficult as the number of players increases. For example, in Wiskin Defense, as more players join, zombies’ strength increases and zombies attack from more than one direction.

We found that there is a risk in using this technique when designing a game for players with different physical abilities. If a player who finds the game difficult to play joins, the increased difficulty may make the game too difficult for the group. We witnessed this problem in Wiskin Defense with P3, who, as discussed earlier, had difficulty timing attacks on the zombies. Playing Wiskin Defense in a group of two was not a problem for any pair of participants, except for pairs including P3. In this case, the difficulty of the game increased at an interval greater than she and the other player were able to compensate for together. This situation is described in the following excerpt from a game session report: “P2 kept telling P3 to wait for him to finish Wiskins and then they would play together [Gekku Race]. He was hesitant about her joining him because then the zombies would come from both sides and he was not going to be able to help her.” This situation
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highlights the importance of carefully scaling for all player abilities as well as the importance of removing in-game barriers for players with differing abilities in order to foster social interactions. In the case of P3, her inability to successfully perform all in-game actions meant she had to wait for P2 to finish before they could play together.

6.5.4 Supporting a variety of play styles

Liberi’s minigames support a range of play styles, including cooperative, competitive, team-based competitive, and solo play. While participants favoured cooperative play, there is evidence that they nonetheless valued having a variety of play styles available. The participants had different preferences in minigames, and sometimes specified different minigames for solo versus group play. To the question: “Which game did you like playing the most with the others?,” eight participants specified Wiskin Defense, two preferred Bobo Ranch, and one listed Gekku Race (one participant chose two games). To the question: “Which one was your favorite game?,” seven participants answered Wiskin Defense, two specified Gekku Race, and one preferred Biri Brawl. Figure 6-4 shows that the competitive Gekku Race and Biri Brawl games were heavily played. This indicates that despite the general preference toward cooperative games, it is important to support a range of game styles both to satisfy individual players’ preferences and to provide a varied experience.

Players proved adept at negotiating among preferences within groups. For example: “There were times P2, P1 and P5 wanted to play different games, but they were able to discuss and to choose the games they would enjoy the most together.” The variety in game styles allowed fluctuating groups to satisfy different participants’ preferences. The negotiation with other players was itself a form of social interaction, helping participants to become familiar with each other.

Having a variety of minigames provided viable game options to players with different abilities. Earlier, we described that P3 had difficulties playing Wiskin Defense and that in one instance, the other player online agreed to change minigames after finishing the one in progress.
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P3 played Gekku Race while she waited for P2 to finish with Wiskin Defense. Despite being a competitive minigame, Gekku Race was a better choice for this group.

6.6 Discussion and lessons for designers

The social aspects of Liberi are especially important for youth with physical disabilities, providing opportunities to socialize, particularly for those for whom leaving the house is difficult. Vital to this goal is the ability for players to interact and communicate, which Liberi delivers through its connected voice chat, supplemented by social media access in the form of a Facebook group. The voice chat proved to be an important component of the game, allowing participants to coordinate group play, share experiences with the others, and sometimes adopt a coaching role to lead group play or teach others how to play a game. We found that players played less when others were unavailable to interact with, meaning it was important that they be able to find times when other players were also online. Participants reported both the voice chat and the Facebook group to be useful in coordinating play times, to ensure they had others to play with.

Liberi is designed to have frictionless grouping mechanisms, enabling players to play whichever minigames they like with any of the other players. Since players cannot be separated by ability without restricting grouping, the game is limited in how it can account for variations in physical ability among the players. This can occasionally cause problems, such as seen above when P2 was reluctant to play Wiskin Defense with P3 (our participant with GMFCS level IV) because he knew the game would become harder. However, we found that players generally did an excellent job performing their own balancing by negotiating which minigames to play together, avoiding the ones that were difficult for individuals in the group. In general, the players were inclusive, working to find a way for all members of the group to play together. This is indicative of the development of strong social links between players. It is particularly interesting that players were able to organically compensate for the imperfections we have identified in our
dynamic difficulty adjustment algorithms, changing minigames when the group composition rendered a minigame too difficult.

Oral communication is of course key to fostering social interaction. We find that in addition to the voice chat aiding engagement in gameplay, the game serves as a seed for conversation. Often in the game session reports, we see that players began the session speaking mostly about issues related to the game, but then as they play, they begin discussing topics unrelated to Liberi. The game provides a ready-made topic for conversation, which then leads to interaction over broader topics. While further study is required, this aspect of the game indicates that Liberi is likely a better forum for social interaction than a simple chat room would be.

In terms of quantitative analysis of Liberi as a social platform, we saw that a large percentage of the time it was possible, players actively played together. We compared this percentage to the drastically lower value reported for what is typical for online games such as World of Warcraft. Liberi is a significantly different game from World of Warcraft, for example, supporting a much smaller population. This result nevertheless suggests that the aspects of Liberi designed to facilitate frictionless group formation—a small easily traversable world, immediate joining of games already in progress, and the simple non-exclusive group formation mechanism—are in fact successful.

A matter for further study is the general preference players have for cooperative games. While it is a small sample of players, it is a fairly strong trend, with seven of the ten players expressing their preference for cooperative play, the most popular game being the cooperative Wiskin Defense, and players transforming the competitive Biri Brawl game into a team game. Testing a version of Biri Brawl in which players are teamed against the bots by default might prove more popular with players. Similarly, it is possible that Pogi Pong would have been played more if the players were on one team and the bots on the other, playing into the cooperative preference.
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6.7 Summary

This chapter showed that it is possible to create networked video games that allow youth with CP to be socially active from the comfort of their home. The results of a ten-week home-based trial using our networked game Liberi were presented, providing evidence based on data collected through the game logs, daily game session reports, questionnaires, interviews and the Facebook group that indicate that each of the high level guidelines used to design the game as a social platform for youth with CP were effective. The guidelines evidenced in these results are: Design for frictionless group formation, Balance for player ability, and Support a variety of play styles.

The following chapter summarizes the contributions and limitations of this thesis. Future areas of investigation are also presented.
Chapter 7

Conclusions and Future Work

Physical limitations in youth with CP make it difficult for them to participate in traditional physical exercise and to engage in social interaction. Exergames represent a promising way of enabling youth with CP to engage in moderately vigorous exercise while allowing them to socialize with others in a fun way. However, commercial exergames and commercial online games are not necessarily suitable for youth with CP, presenting unintended barriers for accessibility in gameplay and social interaction that are difficult to overcome for this population.

Designing exergames that youth with CP can play and use effectively to socialize with others can be challenging. Previous work has proposed guidelines for the development of accessible games for people with motor disabilities. But following these guidelines too literally leads to slow-paced games that require low levels of exercise and that steer away from the types of games that youth with CP find engaging.

The research presented in this thesis provides guidance for the design of fast-paced online exergames that youth with CP at the level III of the GMFCS can play and enjoy with others. The challenge of designing such games was approached through a year-long iterative participatory design process involving medical professionals, game designers, computer scientists, kinesiologists, physical therapists, and a group of youth with CP. During this process, we derived a novel set of guidelines for the design of accessible exergames for youth with CP and a novel set of guidelines for social accessibility in online games for youth with CP. Following these guidelines, we developed an online exergame. The game was evaluated in two home-based studies. The first study focused on evaluating the playability and enjoyment of the game as a means to evaluating the effectiveness of the design guidelines for accessible exergames. The
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second study focused on evaluating the effectiveness of the game in allowing social interaction among youth with CP.

The results of these two home-based trials help validate the two hypothesis proposed in this thesis:

1. By using our new game design guidelines for gameplay accessibility it is possible to design exergames that youth with CP can play and enjoy.
2. By following our new design guidelines for social accessibility, we can allow youth with CP to socially interact with other youth through video games.

Chapter 4 and chapter 6 describe a thorough analysis of the effectiveness of our guidelines for producing accessible gameplay and allowing social interaction among youth with CP.

The following sections describe the contributions, limitations and possible future directions of this research.

7.1 Contributions

This thesis presents four main contributions to the area of human computer interaction, specifically in the design of exergames, which are intended to allow youth with CP to play and enjoy exergames with others. The contributions are:

1. A set of guidelines for the design of exergames for youth with CP that support accessible, fun and engaging gameplay: These guidelines were derived from our experience in designing three fast-paced exergames throughout a participatory design process and were then used to design three more fast-paced exergames. We demonstrated that these guidelines allow the design of exergames for youth with CP that supported accessible, fun and engaging gameplay over an eight-week home-based study.
2. A set of examples that illustrate how to implement these guidelines: We described the design of three fast-paced exergames illustrating how they implement the guidelines for the design of accessible, fun and engaging gameplay. We tested the playability of these
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exergames for youth with CP over our eight-week home-based study. Error! Reference source not found. provides two examples of how each guideline was implemented.

3. A set of guidelines for providing social accessibility in games for youth with CP: These guidelines were derived from the participatory design process for our online game Liberi. We demonstrated that these guidelines allowed the design of an online game that effectively provides social accessibility for youth with CP over a ten-week home-based study.

A set of examples illustrating the implementation of the guidelines for social accessibility: We described the design of our game Liberi showing how our design decisions and a set of tools and methods for interaction with the game exemplify the implementation of the design guidelines for social accessibility. We tested the effectiveness of these tools and methods for allowing social interaction among a group of youths with CP throughout a ten-week home-based study using Liberi. Table 2 offers an alternative view of our guidelines and how they have been implemented.

4. provides two examples of the implementation of each of these guidelines.

7.2 Reflections on the design process

In addition to our four core contributions, we believe that our experience in conducting this type of research can be of help for other researchers in the human-computer interaction field investigating populations with physical limitations.

Working with a special population such as youth with CP introduces challenges that researchers may not anticipate. Here, we describe the most important challenges we faced, and how we were able to circumvent them.

- Designing for people with motor disabilities: The design of exergames for youth with CP required expertise in multiple areas such as in the design of accessible hardware, and understanding of the physical limitations of this target population.
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**Strategy:** To approach these challenges, we formed a multidisciplinary group of researchers. Our research group involved in addition to computer scientists, experts in CP that helped us understand the needs and capabilities of our target population and evaluate the feasibility of alternative solutions. A mechanical engineer brought expertise in the construction of assistive equipment for youth with CP. In addition, we received advice from a professor in exercise psychology and a kinesiologist to determine goals for physical activity for youth with CP through our exergame, and we got feedback on the usability of our game from a professional game designer.

- **Restricted access to the target population:** gathering a group of participants with CP for conducting focus groups and evaluation sessions proved difficult. Special transportation arrangements and an accessible facility were necessary, such as an accessible transportation method, accessible ramps, doors, elevators, and a room where participants could bring their walkers and manual or powered wheelchairs in with them. In most cases, participants and their guardians had time restrictions that limited the frequency and duration of our sessions. It was not practical to use participants without motor impairments as proxies for children with CP, as their capabilities were too different to lend predictive value. Due to these factors, we had to conduct our design and evaluation sessions with a reduced number of participants, usually involving five to six youth split up into two groups, with two hours between sessions.

**Strategies:** In order to make good use of the participants’ time we found it useful to record input data from the participants, and to instrument our game prototypes to run in simulation mode, taking recorded rather than live input for tests at our lab. Another strategy we used was to evaluate several designs in parallel rather than trying to schedule different sessions with different goals. Our sessions included multiple goals such as exploring alternatives for exergaming hardware (bike options, heart rate monitors, game
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controllers), testing game prototypes, and conducting interviews to gather feedback and additional requirements and game preferences.

- **Need for frequent testing:** designing games that are accessible for this population and equipment that is safe and comfortable to use over the several weeks of a home-based study required frequent and thorough testing with the target population before going live.

  **Strategy:** Following each design and evaluation session, adaptations were made to the exercise equipment and exergame, and a follow up session was conducted. We conducted as many design and evaluation sessions as necessary to guarantee that the final equipment and exergame were suitable for an evaluation over several weeks from the participants’ homes. This meant that it took more than a year before we could conduct our first home-based study.

- **Unreliability of qualitative data gathering tools:** We found that some existing usability and game experience questionnaires gave unclear results that did not match our direct observations of the participants. For example, we found that participants frequently reported values to the Children’s OMNI scale of perceived exertion [90] that did not match visual observation, for example reporting values close to minimum-to-no exertion when they were heavily breathing and sweating. We observed that when administering lengthy standard questionnaires with complex vocabulary such as the Physical Activity Enjoyment Scale (PACES) [71] our participants easily lost focus, and frequently required clarification of the questions asked and reported doubtful or unclear answers.

  **Strategies:** We found that when possible, direct observation was critical to gaining an accurate understanding of the participants’ capabilities. We also saw that short and simplified custom built Likert scale questionnaires and open but short interviews were better received by these participants and easier to conduct allowing us to gather more easily the feedback we were interested in.
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- **Participants need for assistance:** The physical limitations of the participants of our home-based studies required that they were assisted in order to be able to get on the exergaming bike, put on the required equipment and start and finish the gaming sessions.

  **Strategies:** We conducted technical training sessions at the home of each participant involving not only the participants with CP but also their parents, caregivers and siblings, so that we could ensure that the participants had someone to assist them when they wanted to join a gaming session. We accompanied the training with a clearly detailed operation manual explaining each step of the start and end of the gaming sessions.

7.3 Limitations

The primary limitations of this thesis are:

- Our guidelines for the design of accessible exergames for youth with CP are intended for the design of fast-paced exergames that aim for improvements in physical fitness. We do not rule out the possibility of using these guidelines to develop games with other purposes; however, we want to point out that some of our guidelines suggest relaxing the accuracy of movement required to play exergames, which might steer away from the nature of some of the games used for slow-paced rehabilitation. Because of this, we suggest a thoughtful selection of our guidelines and additional testing of games produced using them when aiming for games with different purposes.

- Our home-based studies included only participants with CP at GMFCS level III. All these participants were able to pedal unattended using our custom built exergaming station. Participants with a higher level of disability might experience difficulties pedaling without assistance, and therefore, different exergaming equipment and additional testing of the games would be necessary.

- Due to a limited number of exergaming stations, our home-based studies had a limitation of eight participants with CP per cohort. Studies evaluating usability of computing
systems have been found to require only five people to discover 85% of all usability problems [108]. This encourages us to believe that the number of participants involved in our home-based studies (five in the first study and ten in the second study) was adequate for the analysis of our game’s gameplay and social accessibility. Nevertheless, we suggest that our results be interpreted with this limitation in mind.

- One of the goals achieved by this thesis was the design of fast-paced energy-demanding exergames that youth with CP can play. However, the evaluation of these games in terms of their effectiveness at motivating moderately vigorous levels of exercise and at leading to health improvements over the long term is a work in progress. This analysis remains the focus of the broader project CP Fit ‘n’ Fun which explores the health and social benefits of exergaming for youth with CP.

- Our approach to balancing differences in pedaling ability is one of several possibilities of balancing; other balancing techniques for this purpose could be implemented and evaluated. The impact of our balancing technique on the motivation to reach moderately vigorous levels of exercise has not been evaluated as part of this thesis and remains a topic of interest in the broader CP Fit ‘n’ Fun project.

7.4 Threats to validity

The results presented in this thesis should be used and generalized with the following considerations in mind:

- The number of participants in our home-based studies (five in the first study and ten in the second study) might seem low compared to other research in Human Computer Interaction. However, our design process involved ten participants, our eight-week home-based study included four of this ten plus one new participant, and our ten-week home-based study included four from the initial ten participants plus six new, for a total of 17 participants with CP throughout the whole process of designing and evaluating our game.
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Based on the studies suggesting that only five people are necessary for discovering most usability problems [108], we believe that these 17 participants are a significant sample for a valid analysis of the gameplay accessibility of our game. Nevertheless, it is possible that by having a bigger sample size, particularly for the evaluation of the effectiveness of the game as a social venue for social interaction of youth with CP, other issues in group play may be observed.

- Our home-based studies suffered from technical difficulties with heart rate monitors necessary to play the minigames. Players who had a non-working heart rate monitor were required to follow the instructions of an online game monitor to fix the issue and in some cases a research assistant from the hospital had to schedule a visit to replace the heart rate monitor. These technical problems affected the amount of time the participants spent playing and in some cases prevented them from playing for an entire session. These technical problems added a barrier to participation in our home-based studies, which might have affected the motivation of participants to play and the availability of players to play in groups. It is not clear whether other patterns of game usage and social interaction would have been discovered during our field trials if these technical problems had not prevented players from playing more often.

- We designed and evaluated six minigames with different styles; however, it is possible that other styles of games present different issues in playability and group play not discovered during our evaluations.

7.5 Future work

This initial investigation of the design of exergames for youth with CP leads to a series of open questions. Areas requiring further research are presented below.
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7.5.1 Motivating moderately-vigorous exercise
After our first home-based study we found that the game allowed participants to reach moderately vigorous levels of exercise. However, the amount of time over the target heart rate was not always the amount recommended by our exercise prescription. We see an opportunity for refinement of the minigames to improve exertion levels, such as the implementation of heart rate-based rewards, identification and redesign of areas in the minigames that allow players to rest or require slow pedaling, and reduction of the time players spend traveling around the island. While heart rate-based rewards have already been implemented into the game, the implementation of the other techniques is a work in progress. A proper evaluation of the games after the implementation of these techniques is also future work.

7.5.2 Balancing techniques
As described above, we implemented one out of several possibilities for balancing differences in pedaling ability in the game. The effectiveness at motivating moderately vigorous levels of exercise of games using this balancing technique remains a question to explore.

Other balancing techniques could also be implemented and evaluated in this game. One alternative is effort-based balancing, where the players’ effort is considered to adjust the difficulty of the game. One example of this approach is the one proposed by Stach, et al. [101] where heart rate is used as a measure of effort. A balancing technique where the resistance of the bike is dynamically adjusted based on the player’s abilities or effort might become possible in the future with the release of biking units providing open interfaces to dynamically adjust the resistance from a computer.

7.5.3 Support for more players online at the same time
We found that the strategy of using a global voice chat for all the participants of the game worked well for a maximum of eight participants. In addition, due to the availability of our specialized exergaming equipment, our studies had a limitations of a maximum of eight players in a single
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cohort. Additional research is necessary to identify what specific considerations or adjustments would be necessary to allow a bigger number of players playing the game online at the same time.

7.5.4 Application to other populations

Our target population is significant in numbers: 67.7% of the roughly 800,000 people with CP in the U.S. are classified at GMFCS levels I, II or III [56]. It is nevertheless interesting whether our results can be transferred to other populations, such as those with spinal cord injuries, motor disabilities due to stroke, or people with more involved categories of CP.

One participant in our participatory design process who was at GMFCS level IV required assistance pedaling. This participant nevertheless thoroughly enjoyed playing. We cautiously hypothesize that with an appropriate pedaling device, this style of game might be adaptable for people with more involved forms of CP. To extend the games to people with different forms of motor disability, testing will be required. For patients with spinal cord injury, for example, it would be interesting to adapt a hand mounted pedaling device combined with our one-button interface, similar to that used by Widman et al. [117].

7.5.5 Deployment of the game for its use at home

In order to deploy the game for its use from home, technical difficulties observed during our studies, such as the one with heart rate monitors, need to be solved. The size of our groups of participants was also limited by the number of specialized exergaming stations we had available, in part due to their high cost (~2,000 CAD per unit). We have seen an overwhelming wave of technological developments in the health and fitness industry in recent years, and we believe that there are opportunities for improving the stability and cost of our system in these technological developments. We strongly recommend that any alternative technologies be tested with the actual population of people with CP to determine its suitability and reliability.
Chapter 7: Conclusions and Future Work

7.6 Summary

In this thesis we have shown that guidelines for the design of accessible fast-paced gameplay and guidelines for the design of accessible social interaction in online games are useful for the design of games that youth with CP can use to engage in moderately vigorous exercise and social interaction with others. Two home-based studies found that a game built following these guidelines in fact allowed players with CP to exercise and socialize over eight and ten weeks. We saw that even though our guidelines produce fast-paced games that are accessible, they do not guarantee that they are enjoyable. Game designers might want to make thoughtful use of our guidelines when designing games with different styles to those presented in this thesis and also when targeting a population with different levels of physical disability. We believe that the most effective way of determining the playability and fun of video games for a specific population is by conducting rigorous tests with the target population.

We believe that the contributions of this thesis are a leveraging step to producing games that might improve the quality of life of people with motor disabilities.
References


References


143
References


References


References


References


References


References


References


150
References


Appendix A
Data Collection Tools for Participatory Design Sessions
Feedback questionnaire for Liberi minigames

Participant ID: _______ Age: _______ Gender: M_______ F_______

Please answer the next questions based on your experience with the game you just played.

### Dozo Quest

<table>
<thead>
<tr>
<th>Administered after playing the game</th>
<th>Strongly Agree</th>
<th>Somewhat Agree</th>
<th>Neutral</th>
<th>Somewhat Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Game play</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The goal of the game is clear and simple</td>
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</tr>
<tr>
<td>This game was easy to play</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fun</td>
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<td></td>
</tr>
<tr>
<td>I had fun playing the game</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>This game was challenging</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exertion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>This game was physically tiring</td>
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</table>

### Bobo Ranch

<table>
<thead>
<tr>
<th>Administered after playing the game</th>
<th>Strongly Agree</th>
<th>Somewhat Agree</th>
<th>Neutral</th>
<th>Somewhat Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Game play</td>
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<tr>
<td>The goal of the game is clear and simple</td>
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<tr>
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<tr>
<td>Fun</td>
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<tr>
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<tr>
<td>This game was challenging</td>
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<tr>
<td>Exertion</td>
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<tr>
<td>This game was physically tiring</td>
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</table>

### Gekku Race

<table>
<thead>
<tr>
<th>Administered after playing the game</th>
<th>Strongly Agree</th>
<th>Somewhat Agree</th>
<th>Neutral</th>
<th>Somewhat Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Game play</td>
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<tr>
<td>The goal of the game is clear and simple</td>
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<tr>
<td>This game was easy to play</td>
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<tr>
<td>Fun</td>
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<tr>
<td>I had fun playing the game</td>
<td></td>
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<tr>
<td>This game was challenging</td>
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<tr>
<td>This game was physically tiring</td>
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</tr>
</tbody>
</table>
Appendix A: Data Collection Tools for Participatory Design Sessions

Open questions for discussion at the end of each session

- What did you like the most in the Dozo Quest game?
- What did you think was fun in Dozo Quest?
- What did you not like in the Dozo Quest game? What would you like instead?

- What did you like the most in the Bobo Ranch game?
- What did you think was fun in Bobo Ranch?
- What did you not like in the Bobo Ranch game? What would you like instead?

- What did you like the most in the Gekku Race game?
- What did you think was fun in Gekku Race?
- What did you not like in the Dozo Quest game? What would you like instead?
Appendix B
Sheets for Home-based Trial 1: Gameplay Accessibility of Liberi
Appendix B: Sheets for Home-based Trial 1: Gameplay Accessibility of Liberi

8-week progressive exercise prescription for youth with cerebral palsy

<table>
<thead>
<tr>
<th>Program Stage</th>
<th>Week</th>
<th>Frequency (days/week)</th>
<th>%HRmax</th>
<th>%HRR</th>
<th>RPE</th>
<th>Breathing Rate</th>
<th>Duration (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Stage</td>
<td>1</td>
<td>3</td>
<td>64-70</td>
<td>40-50</td>
<td>2-4</td>
<td>Slightly Increased</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3</td>
<td>64-70</td>
<td>40-50</td>
<td>2-4</td>
<td>Slightly Increased</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3</td>
<td>70-77</td>
<td>50-60</td>
<td>3-5</td>
<td>Noticeably Increased</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>3</td>
<td>70-77</td>
<td>50-60</td>
<td>3-5</td>
<td>Noticeably Increased</td>
<td>30</td>
</tr>
<tr>
<td>Improvement and Maintenance</td>
<td>5</td>
<td>3</td>
<td>77-80</td>
<td>60-70</td>
<td>3-5</td>
<td>Noticeably Increased</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>3</td>
<td>77-80</td>
<td>60-70</td>
<td>3-5</td>
<td>Noticeably Increased</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>3</td>
<td>77-80</td>
<td>60-70</td>
<td>4-6</td>
<td>Noticeably Increased</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>3</td>
<td>77-80</td>
<td>60-70</td>
<td>4-6</td>
<td>Noticeably Increased</td>
<td>40</td>
</tr>
</tbody>
</table>

HRmax - maximum heart rate; HRR - heart rate reserve; min - minutes; RPE - Rating of Perceived Exertion (10 Scale)

Appendix B: Sheets for Home-based Trial 1: Gameplay Accessibility of Liberi

### Post-intervention field trial game questionnaires

Please answer the next questions based on your experience with the games played during the Field Trial.

<table>
<thead>
<tr>
<th>Game</th>
<th>Dozo Quest (The spikeball game)</th>
<th>Strongly Agree</th>
<th>Somewhat Agree</th>
<th>Neutral</th>
<th>Somewhat Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The goal of the game is clear and simple</td>
<td></td>
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<tr>
<td></td>
<td>This game was easy to play</td>
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<tr>
<td></td>
<td>I had fun playing the game</td>
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<tr>
<td></td>
<td>This game was challenging</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>This game was physically tiring</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Game</th>
<th>Biri Brawl (The jellyfish game)</th>
<th>Strongly Agree</th>
<th>Somewhat Agree</th>
<th>Neutral</th>
<th>Somewhat Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The goal of the game is clear and simple</td>
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<td></td>
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<td></td>
<td>This game was challenging</td>
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<td>This game was physically tiring</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Game</th>
<th>Wiskin Defense (Zombie defense game)</th>
<th>Strongly Agree</th>
<th>Somewhat Agree</th>
<th>Neutral</th>
<th>Somewhat Disagree</th>
<th>Strongly Disagree</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>The goal of the game is clear and simple</td>
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<td></td>
<td>I had fun playing the game</td>
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<tr>
<td></td>
<td>This game was challenging</td>
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<td></td>
<td>This game was physically tiring</td>
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</tbody>
</table>
### Appendix B: Sheets for Home-based Trial 1: Gameplay Accessibility of Liberi

<table>
<thead>
<tr>
<th>Game play</th>
<th>Gekku Race</th>
<th>Strongly Agree</th>
<th>Somewhat Agree</th>
<th>Neutral</th>
<th>Somewhat Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The goal of the game is clear and simple</td>
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<td></td>
<td>This game was easy to play</td>
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<tr>
<td>Fun</td>
<td>I had fun playing the game</td>
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<tr>
<td></td>
<td>This game was challenging</td>
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<tr>
<td>Exertion</td>
<td>This game was physically tiring</td>
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</table>

<table>
<thead>
<tr>
<th>Game play</th>
<th>Bobo Ranch (Sheep herding game)</th>
<th>Strongly Agree</th>
<th>Somewhat Agree</th>
<th>Neutral</th>
<th>Somewhat Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The goal of the game is clear and simple</td>
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<td>This game was easy to play</td>
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<tr>
<td>Fun</td>
<td>I had fun playing the game</td>
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<tr>
<td></td>
<td>This game was challenging</td>
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<table>
<thead>
<tr>
<th>Game play</th>
<th>Pogi Pong (Space hockey game)</th>
<th>Strongly Agree</th>
<th>Somewhat Agree</th>
<th>Neutral</th>
<th>Somewhat Disagree</th>
<th>Strongly Disagree</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>The goal of the game is clear and simple</td>
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<tr>
<td></td>
<td>This game was easy to play</td>
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</tr>
<tr>
<td>Fun</td>
<td>I had fun playing the game</td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>This game was challenging</td>
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<td>This game was physically tiring</td>
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</tr>
</tbody>
</table>

### Semi-structured interview with participants

Ask the top level questions and drill down to the second level ones if the participant is not giving much information.

1. Which games would you say were the most fun/engaging during the study?
2. Which games would you say required you to plan and think in order to do better?
3. Which games would you say were difficult to play/control the avatar?
Appendix B: Sheets for Home-based Trial 1: Gameplay Accessibility of Liberi

4. Did you prefer the games where you had to compete with the other players like Biri Brawl (Jellyfish game) and Gekku Race, the games where you had to cooperate with the others like Bobo Ranch and Wiskins Defense, or the games you could play alone like Dozo Quest?

5. Which games did you like playing the most with the others?
Which game did you prefer when there was no one to play with?

6. What did you like the most in Liberi?
   a. Which one was your favorite game?
   b. Do you think that having a voice communication system makes playing with others more fun or maybe more motivating?
   c. Did you find yourself pedaling more or harder when playing alone or playing with the others?

7. What did you not like in Liberi?
   a. Was there any game you did not like?
      What would you change in this game to make it better?
   b. Which game did you play the least?
   c. Did you have any difficulties playing around the island or any of the minigames?

8. What game did you find the most physically tiring?

About different approaches for managing the field trial

Ask the participants the top level question and drill down to the second level ones if the participant is not giving much information.

1. Did you find it important having someone on-line monitoring the gaming sessions?
   a. Were the monitors useful for troubleshooting?

2. Did you find the weekly coaching calls important?
   a. Do you think they are useful for reporting and solving problems?
Appendix B: Sheets for Home-based Trial 1: Gameplay Accessibility of Liberi

b. Do you think they are important for encouraging play?

3. Did you find it important to have a Facebook group?
   a. Was it useful for encouraging play?
   b. Was it useful for troubleshooting?
   c. Was it useful for communicating with the other players?

4. What method did you like the most to schedule playing times with the other players?
   (Facebook, phone, the gaming sessions themselves, the weekly coach call).

5. Did you find the troubleshooting option of using a pager useful? Why?
Appendix C
Sheets for Home-based Trial 2: Social Accessibility of Liberi
**Appendix C: Sheets for Home-based Trial 2: Social Accessibility of Liberi**

**10-week progressive exercise prescription for youth with cerebral palsy**

<table>
<thead>
<tr>
<th>Week of Intervention</th>
<th>Goal</th>
<th>Upper Limits</th>
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<td>Frequency / week</td>
<td>Intensity</td>
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<td>3</td>
<td>40%</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
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<td>3</td>
<td>45%</td>
</tr>
<tr>
<td>10</td>
<td>3</td>
<td>45%</td>
</tr>
</tbody>
</table>

*or 60 minutes of general activity.
Appendix C: Sheets for Home-based Trial 2: Social Accessibility of Liberi

Post-intervention field trial game questionnaires

Please answer the next questions based on your experience with the games played during the Field Trial.

<table>
<thead>
<tr>
<th>Gekku Race</th>
<th>Strongly Agree</th>
<th>Somewhat Agree</th>
<th>Neutral</th>
<th>Somewhat Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Game play</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>The goal of the game is clear and simple</td>
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<td></td>
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<tr>
<td>This game was easy to play</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fun</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>I had fun playing the game</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>This game was challenging</td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>Exertion</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>This game was physically tiring</td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Biri Brawl</th>
<th>Strongly Agree</th>
<th>Somewhat Agree</th>
<th>Neutral</th>
<th>Somewhat Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
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### Appendix C: Sheets for Home-based Trial 2: Social Accessibility of Liberi

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**Semi-structured interview with participants**

Ask the top level questions and drill down to the second level ones if the participant is not giving much information.

1. Which games would you say were the most fun/engaging during the study?
2. Which games would you say required you to plan and think in order to do better?
3. Which games would you say were difficult to play/control the avatar?
Appendix C: Sheets for Home-based Trial 2: Social Accessibility of Liberi

4. Did you prefer the games where you had to compete with the other players like Biri Brawl, Pogi Pong and Gekku Race, the games where you had to cooperate with the others like Bobo Ranch and Wiskins Defense, or the games you could play alone like Dozo quest?

5. Which games did you like playing the most with the others?
Which game did you prefer when there was no one to play with?

6. What did you like the most in Liberi?

d. Which one was your favorite game?

e. Do you think that having a voice communication system makes playing with others more fun or maybe more motivating?

f. Did you find yourself pedaling more or harder when playing alone or playing with the others?

7. What did you not like in Liberi?

d. Was there any game you did not like?
What would you change in this game to make it better?

e. Which game did you play the least?

f. Did you have any difficulties playing around the island or any of the minigames?

8. What game did you find the most physically tiring?

9. How did you find the special abilities based on reaching your target HR?

a. How hard did you find to get these special abilities?

10. How did you find the mechanics in the game for warming up, cooling down and slowing down (when you were working too hard) (pedalatypus)?

11. How did you find the game schedule release?

a. Do you think that there were not many games available to play at some point?

b. Is there any game you think should have been released earlier?
Appendix C: Sheets for Home-based Trial 2: Social Accessibility of Liberi

c. Did knowing that more games would be released motivate you to keep coming back to play?

**About different approaches for managing the field trial**

Ask the participants the top level question and drill down to the second level ones if the participant is not giving much information.

6. Did you find it important having someone on-line monitoring the gaming sessions?
   a. Were the monitors useful for troubleshooting?

7. Did you find the weekly coaching calls important?
   a. Do you think they are useful for reporting and solving problems?
   b. Do you think they are important for encouraging play?

8. Did you find it important to have a Facebook group?
   a. Was it useful for encouraging play?
   b. Was it useful for troubleshooting?
   c. Was it useful for communicating with the other players?

9. What method did you like the most to schedule playing times with the other players?
   (Facebook, phone, the gaming sessions themselves, the weekly coach call).

10. Did you find the troubleshooting option of using a pager useful? Why?