iGYM: An Interactive Floor Projection System for Inclusive Exergame Environments

Roland Graf[1], Pallavi Benawri[2], Amy E Whitesall[2], Dashiell Carichner[3], Zixuan Li[4], Michael Nebeling[2,4], and Hun Seok Kim[4]

[1] Penny W. Stamps School of Art & Design, University of Michigan, Ann Arbor, MI, USA

[2] School of Information, University of Michigan Ann Arbor, MI, USA

[3] School of Kinesiology, University of Michigan, Ann Arbor, MI, USA

[4] Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI, USA

{rolgraf, pbenawri, amycarss, carichnd, henryli, nebeling, hunseok}@umich.edu

ABSTRACT

In traditional sport settings, players with mobility disabilities typically do not have opportunities to engage in physical play with their peers without mobility aids and vice versa. In this paper, we present an interactive floor projection system, *iGYM*, designed to enable people with mobility disabilities to compete on par with, and in the same physical environment as, their peers without disabilities. At the core of *iGYM* are the concept of peripersonal circle interaction and adjustable game mechanics, which enable individualized game calibration and wheelchair-accessible manipulation of virtual targets on the floor. Based on a pilot study, we determined three adaptation levels designed to make the system *(I)* accessible, *(II)* more playable, and *(III)* more balanced. We conducted a user study with 12 children testing the effects of these levels. Findings indicate that higher adaptation levels were not always preferred. Player preferences were multifactorial and also based on their desire to challenge themselves. Perceptions of fairness were often formed regardless of whether players used wheelchairs or not.

Author Keywords

Adaptive sport; inclusive exergame; interactive floor; game balancing; peripersonal space.

CSS Concepts

• **Human-centered computing~Accessibility technologies**
• Human-centered computing~Mixed / augmented reality

INTRODUCTION

Adaptive sports, and more recently exergames, have successfully enabled people with mobility disabilities to enjoy the benefits of physical play. For example, wheelchair basketball, tennis, quad rugby and power soccer provide many benefits beyond physical fitness including an increased sense of empowerment, normalcy, and acquisition of social capital [29]. However, adaptive sports typically do not address the physical and social barriers [39, 45] that limit the opportunities, particularly for young people with mobility disabilities, to engage in physical play activities with their non-disabled peers [32]. Likewise, exergames for people with mobility disabilities often focus on improving their rehabilitation outcome, but do not address their needs for recreational exercise and social inclusion in communities. Further, many popular exergame platforms (e.g., Nintendo Wii or Xbox Kinect) or custom-designed exergame interventions for players with disabilities are screen-based [23, 24, 35], which is impractical for co-located play scenarios [44] similar to adaptive sports or sport activities in general.

Figure 1. Two children competing on iGYM's interactive floor. The projected circles around their bodies can be expanded – through body movement or with a kick button – to manipulate a virtual target into the opponent's goal. The scores are displayed at the center of the playfield.

CHI PLAY '19, October 22–25, 2019, Barcelona, Spain

ACM ISBN 978-1-4503-6688-5/19/10…$15.00
DOI: https://doi.org/10.1145/3311350.3347161

In this paper, we propose to use projected augmented reality (AR) in the form of an interactive floor system to facilitate co-located physical play experiences for people with mobility disabilities and their non-disabled peers (see Figure 1). Interactive floor systems and their potential to facilitate whole-body interactions and co-located games have been studied mostly for people with cognitive disabilities [22, 46, 47] or non-disabled people [8, 20, 33]. Further, many interactive floor systems have been deployed commercially (e.g., most notably interactive floor projections in shopping malls or museums), but no system has been developed and implemented yet for people with mobility disabilities in inclusive traditional sport settings.

Our main contribution is a wheelchair-accessible projected AR sport system, *iGYM*, designed to enable people with different abilities and mobility aids to engage in realistic manipulation of virtual targets on an interactive floor. Our current implementation of *iGYM* is an air hockey inspired multiplayer game. Two key design features of *iGYM* are: ***(1)*** **peripersonal circle interaction**, a projected circle on the floor visualizing each player's peripersonal space boundaries with which they can manipulate a virtual target on the floor by body movement, limb extension or pressing a kick button to simulate limb extension; ***(2)*** **adaptable game mechanics** using physics simulation to create a realistic ball game environment, which allows balancing players' individual differences in response time or mobility by controlling game mechanics such as the circle size and puck speed and customizing them for each player.

We evaluated the effectiveness of *iGYM* to accommodate different abilities and mobility aids in this game. In a pilot study, we first identified three adaptation levels to adjust the peripersonal circle interaction for a variety of match-ups between players using power wheelchairs, players using manual wheelchairs, and players without wheelchairs. Each level uses an increased adaptation condition of the peripersonal circle interaction. In condition CI, the presence of the peripersonal circle makes the game accessible for players with varying mobility. Condition CII improves the game's playability by providing players who use wheelchairs with a way to momentarily expand their peripersonal circle using a kick button. Condition CIII employs a game balancing model in addition to providing a kick button for players who use wheelchairs.

We then conducted a user study with 12 children (9-16 yrs. old) including five players using power wheelchairs, three players using manual wheelchairs, and four players without wheelchairs. *iGYM* enabled fast paced 1-on-1 competitions in different match-ups. Findings suggest that playing the game in adaptation level *CIII*, the most adapted and balanced condition, was slightly preferred. Most players preferred matches in which the kick button enhanced the playability for players using wheelchairs (condition *II+III*) over matches without the kick button (condition *I*). Preferences, however, were multifactorial and also based on players' interest in challenging themselves, and perceptions of fairness were often formed regardless of whether players used wheelchairs or not.

RELATED WORK

Our proposed system builds on prior work on adaptive sports, exergame accessibility, game balancing, co-located games on interactive floors, and peripersonal space.

Adaptive Sports

Through adaptive sports, people with disabilities learn compensatory strategies and transform their perceptions of self by building strength, flexibility, stamina, and an improved outlook on life [38]. Adaptive sports also create a unique opportunity for technological innovation. Wheelchair sports in particular have been a driving force for innovation in adaptive sports technology and practice [9]. An example is Power Soccer, a competitive team sport for users of motorized wheelchairs, who are unable to propel themselves in manual wheelchairs or perform the feats of upper-body strength that manual wheelchair sports require [35]. Power Soccer is most related to the play opportunities and experiences that our proposed system seeks to provide. It enables co-located physical play by optimally using all the resources at hand [43]. For example, in Power Soccer, players use a foot guard as an intermediary object or tool to kick an oversized soccer ball, which is an input modality that shares some similarities with our proposed peripersonal circle interaction. However, power soccer has yet to explore opportunities for greater social integration in which people with disabilities can play together with their peers without disabilities.

Exergame Accessibility

Active video games or exergames encourage physical activity by enabling players to use bodily movements to control the gameplay. The emerging body of literature exploring the design of exergames accessible to players with disabilities typically focuses on at least one of three different aspects: the games' socialization, entertainment, and rehabilitation outcomes [21]. The latter is the primary focus of the majority of studies that explore exergames as a way of improving motor skills and cardiovascular outcomes. Fewer studies focus on entertainment or socialization aspects in correlation with accessibility concerns of player with disabilities [23, 24, 35]. A particular related sub-category of exergames for players with disabilities are wheelchair-based movement games [15, 18] in which the wheelchair movement and position becomes part of the element that controls the game. A common limitation of such exergame interventions is that regardless of their system input accessibility, their system output is typically screen-based limiting the playfield to a virtual space disconnected from the physical space surrounding the players. In other words, these games preference single player scenarios or scenarios in which multiple players face the same screen, which restricts co-located play opportunities [43] that allow players to engage with each other in shared physical space, for example, by augmenting it with minimal visual aids like *iGYM*.

Game Balancing

Balancing games helps to keep players in the state of Flow [10] by balancing their abilities with the challenges that they encounter [30]. Jackson and Csikszentmihalyi [28] argue that for the experience of Flow, the perception of a challenge is more important than the apparent objective challenge. For example, a stronger tennis player can enjoy competing against a weaker player by choosing to change their focus from winning the game to setting goals for improving different aspects of their game. This balances the challenge for the optimal experience. Jackson and Csikszentmihalyi, therefore, make a basic distinction between person-centered and environment-centered challenge adjustments [28]. This distinction also inspired Altimira et al's [1] internal and external adjustment dimensions for balancing exertion games, which seem particularly relevant for game adaptations in traditional sport settings.

Particularly related to our design goal of having people with disabilities compete on par with their peers without disabilities is Wheelchair Revolution, a competitive motion-based dancing game [17]. This game allows explicit and hidden balancing approaches to accommodate players' different skills and abilities in a screen-based setting. Such balancing approaches, which are also known as player balancing [7] and typically involve altering game mechanics to provide hindrance or assistance to one of the players, have been shown to be particularly important for making exergames accessible and fair for players with mobility disabilities. For example, Hwang et al. [26] found an increase of perceived fun and fairness, and reduction in "blowout" races with large score differentials when an algorithm was used to balance differences in pedaling ability among children with cerebral palsy competing in a screen-based racing game. Prior research also indicates that players in social play settings are more likely to accept explicit game balancing assistance because it promotes playing together with friends [14]. Little is known, however, about the effects of similar game balancing strategies in a traditional sport setting on the performance or experience of players with disabilities competing with peers without disabilities and vice versa.

Co-located Games on Interactive Floors

Interactive floors encourage physically active behavior by enabling co-located physical play. A systematic review of co-located augmented play spaces [13] places interactive floors in the category of interactive screen environments. The most widely used commercial deployment of interactive floors comes in the form of ceiling mounted projection and motion-monitoring systems. Müller et al. [41] provide a technical review of the most common interactive floor systems and propose a novel interactive laser floor system, which we also consider as a possible direction for our future system. Studies on interactive floors show their potential to facilitate co-located and collaborative games. Most of those studies focus on non-disabled players [8, 20, 33] or players with cognitive disabilities [22, 46, 47], but not on players with mobility disabilities in inclusive settings.

Particularly related to the spatial and technical configuration of our proposed system is the FUTUREGYM project [46], a large-scale interactive floor projection system in a school setting meant to provide social skill training for children with cognitive disabilities. This project follows the paradigm of spatial augmented reality and projects only minimal visual aids on the floor, which leverages its ability to function even with the light levels of a typical exercise environment. It uses multiple projectors and large ceiling heights, which helps prevent occlusion. However, it does not provide the design features to enable co-located physical play experiences for people with mobility disabilities and their non-disabled peers.

Further, related to our air hockey inspired game with peripersonal circle interaction is a recent demonstration of a German glass flooring system manufacturer [2]. This demonstration shows a similar multiplayer sport environment making use of interactive floor tiles. However, the tracking in this system can only sense the players' feet and the circle does not dynamically adapt to the player's peripersonal space boundaries.

Peripersonal Space

The concepts of peripersonal space and body schema have direct implications for the design of the peripersonal circle feature. According to these concepts, guiding the movement of the body through space and manipulating objects requires an integrated neural representation of the body (i.e., the body schema) and of the space around the body (i.e., the peripersonal space) [25]. Further, and key for the better understanding of the two input modalities of our peripersonal circle feature (i.e., extending limbs and pressing a push button), are studies showing that peripersonal space boundaries can be modulated both by extending limbs or using tools. Examples of tool use include navigating with a cane, playing tennis with a racket [4], using a computer mouse [3], or using a wheelchair as a full-body tool [16]. We believe that interactive environments, such as our proposed interactive floor, provide similar opportunities for peripersonal space boundary modulation and full body illusions, in which the peripersonal space representation shifts from the physical body to a subjectively experienced virtual body [42].

THE IGYM SYSTEM

In this section, we describe the design process and the main system components of *iGYM*. An earlier version of *iGYM* with a preliminary user study was presented in [19], following which we developed new features for the *iGYM* system, introducing a more structured approach to the adjustable game mechanics based on three player-driven adaptation levels. We also developed an automatic adaptation approach based on a new game balancing model and a single-player training mode. We evaluated these new aspects in a new user study with 12 children.

Design and Development Process

The complete design and development process from low to high fidelity prototypes was informed by interviews with health professionals in a customer discovery program following the Lean LaunchPad approach [5] and casual observations of physical therapy sessions of people with mobility disabilities. Further, it was informed by constant usability and playtesting, first by our research team members, and then by "tissue testers" [43] ranging from 4-12 years old. Our design and development strategy was to first assure the overall quality of our prototype before conducting pilot playtests with players using mobility aids to minimize frustration from unwanted or unresolved functionality issues.

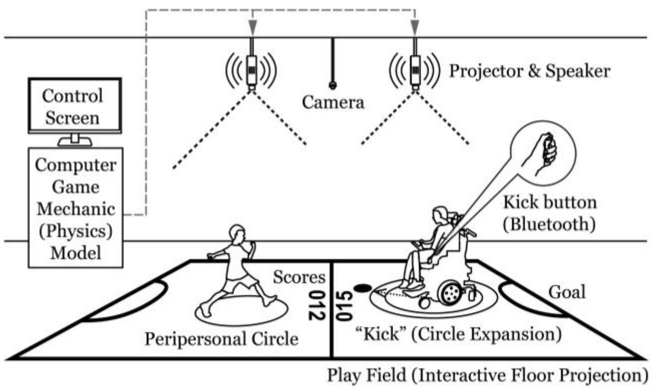

Figure 2: iGYM concept. Players' peripersonal circles can be expanded to "kick" a target on the interactive floor via limb movement or kick button activation.

Peripersonal Circle Interaction and Kick Button

The *iGYM* concept is shown in Figure 2. *iGYM* projects a circle on the floor around each detected player that enters the playfield. The center of each of these peripersonal circles is initially obtained by the weighted average of coordinates of all the pixels constituting the shape of the detected player. The size of each circle is refined via the trimming and dilation process performed on the detected player shape. As a result, the circle's center travels, and the perimeter expands or contracts based on the player's movement representing the peripersonal space boundary. For example, the player's arm extension or kicking motion increases the area of active pixels of the detected player and expands the circle projection around the body accordingly. This responsive circle can be used to directly manipulate (e.g., "kick") a virtual target such as a puck on the floor.

For players who may not be able to easily extend their arms or perform a kick, we introduced a wireless controller with a kick button to expand their peripersonal circle representation and achieve the same effect (Figure 3). This

Figure 3: Two examples of kick button activation; knee (left player) and index finger (right player).

Figure 4. Researcher demonstrating the kick button controller prototype based on a modified Bluetooth wireless mouse.

kick button can be attached to the body (e.g., hand, finger, torso, or leg mounted) or to the mobility aid. Our current controller prototype is a modified Bluetooth wireless mouse that allows plugging in switches with different form factors (Figure 4). For our study, we used two different switches with an activation surface of 2.5cm and 3.5cm diameter. Both switches provide an auditory click and tactile feedback. Players could choose between these two switches and their mounting position. The smaller switch could be attached to the index finger of players using manual wheelchairs with athletic pre-wrap in such a way that they could activate the switch while pushing the wheelchair hand rims, and a larger button could be placed in the hand of players using power wheelchairs or body-mounted with hook-and-loop strips.

Adjustable Game Mechanics

The game mechanics in *iGYM* are based on a set of adjustable game parameters and physics simulation, which together allow realistic and fast-paced interaction with a virtual target on the floor bouncing off playfield boundaries as well as the players' peripersonal circles. *iGYM* supports manual balancing of players' individual differences in response time or processing speed by allowing game mechanics' parameter customization for each player and each side of the playfield individually (see Table 1).

We used this feature to develop a competitive game for two players inspired by air hockey. In this game, the playfield is divided into two parts, each dedicated to one player, who

Global Parameters	Default*
Target diameter (m)	0.36
Individual Parameters for each Player & Playfield Side	
Min target speed (m/s)	0.08
Max target speed (m/s)	5.86
Goal size for scoring (m)	2.1
Playfield friction (m/s^2)	0.33
Playfield boundary elasticity for target contact (%)	90
Individual Parameters for Kick Button	
Max diameter of expanded peripersonal circle (m)	2.52
Max speed of peripersonal circle expansion (m/s)	20
Max hold time of expanded peripersonal circle (s)	1.5

Table 1: Key parameters for game calibration. *Parameter baseline used in adaptation condition *CI* + *CII*.

can score and defend goals similar to playing air hockey or soccer. Some of the key parameters that are used for game play adjustment and player balancing are listed in Table 1.

For example, the maximum speed of the target and the size of the goal set the overall pace and difficulty of the game. Playfield friction determines how fast the target decelerates on each side of the playfield. Applying a higher friction setting on one side would make the target move slower when it enters that region. The elasticity parameter determines the deceleration of the target on each side of the playfield when it contacts the peripersonal circle or playfield boundary. Related to the kick button are the parameters that set the speed with which the peripersonal circle expands, the maximum size it expands to, and the maximum hold time or duration it can be kept expanded (e.g. to defend a goal).

Game Balancing Model

We also developed a game balancing model in iGYM that can be automatically trained in a short single-player session against the system (a pre-test). A simple linear performance model is adopted to estimate the expected player score (PS) as a function of two game parameters: goal size (GS) and peripersonal circle (PC) size. In our linear model, the player score performance PS is estimated by three coefficients a, b, and c using an equation $PS = aGS + bPC + c$ for a given GS and PC parameter set. Each user plays a short 4-minute single player game with various GS and PC parameter settings while the system records the current player's score for a specific parameter setting (GS, PC). When a single player game completes, linear model parameters a, b, and c are extracted by solving a least square problem [37]. By adjusting peripersonal circle size, the system then increases or counterbalances each player's reach advantage based on their performance.

Spatial and Technical Configuration

iGYM has been implemented in a large common space of a university studio building with ceiling heights (6.8m) and light levels (~270 lux) similar to those of a school gym (see Figure 3). Two ceiling mounted projectors with integrated loudspeaker (Epson Pro G7100 XGA 3LCD, 1024x768 pixels, 6500 lumens) create a 6.3 x 4.2 m large projection area on the floor. For better projection visibility, the floor is covered with a white skid resistant PVC covering. A ceiling mounted camera (StereoLabs ZED camera, 1280x720 pixel) monitors the players' movements. It captures graphic frames and streams them to the host computer (Intel Core i7-6700 CPU @ 3.40GHz * 8) at a constant rate of 35 frames per second (fps). The system output is reduced to minimal visual projections on the floor such as court lines, markings, scores, targets, and the peripersonal circle feature, enhanced by some sound effects. As a result of this system configuration, players are less likely to obscure a projection and occlusion is in general less noticeable.

PILOT STUDY TO EXPLORE GAME PARAMETERS

To develop an appropriate study design and select adaptation parameters for our system, we conducted pilot playtests with 9 participants between 7 and 19 years old, including 7 people with mobility disabilities (5 power wheelchair users, 2 manual wheelchair users) and 2 players without disabilities.

Playtests were conducted over three separate days. We formed three groups of players *(1)* using the same, *(2)* using different, and *(3)* using no mobility aids. Players were paired up to compete against each other in these constellations in 10-minute-long playtest sessions. During a warm-up phase, game parameters such as circle expansion speed and goal size were determined based on our observations, while the preferred mounting position and form factor of the kick button were chosen in consultation with each player.

For the pilot study, we collected observational and informal interview data from players and their caregivers. Interview questions focused on the usability of the peripersonal circle interaction feature in conjunction with the kick button and the pace of the game. To complement our field observation data, we also recorded quantitative measures such as the ball speed to determine the overall pace of the game and the "kicking power."

Observations

In general, our pilot study showed that *iGYM's* air hockey game was accessible for all participants. Our main observations relate to the peripersonal circle interaction and kick button, the target speeds, and goal size adaptation.

Peripersonal circle interaction and kick button

The peripersonal circle interaction feature was accessible and intuitive to use for all players, especially when the target was in front of the players. Some wheelchair users struggled when the target was behind their backs. Two power wheelchair users and one player without disabilities highlighted independently the peripersonal circle feature and the kick button as their *"favorite parts"* and the elements that make the game *"fair"*. For the kick button, we determined that the two switch form factors (2.5cm and 3.5cm) were sufficient to accommodate all pilot participants using wheelchairs. The primary mounting positions were hands, legs, and knees. The click and hold function of the kick button enabled wheelchair users to perform similar gameplay behavior as their peers without disabilities. For example, it enabled the players to push the button for a kick or hold it down to keep the peripersonal circle expanded to block an opponent's kick and defend the goal.

Adjustable game mechanics

iGYM's game mechanics created a realistic air hockey inspired game experience and helped to set its overall pace. We adjusted various parameters to test their effects, including the target speed, playfield friction, and playfield boundary elasticity. However, slowing down or increasing the speed for each player or playfield side individually seemed to disrupt the game's flow and was deemed less practical. Further, speed parameter adjustments seemed less significant as a potential player balancing approach compared to the effects of adjusting the size of the peripersonal circle or the size of the goal. While adjusting the peripersonal circle size was perceived as providing assistance, adjusting the goal size was mostly perceived as changing the difficulty level for players. We decided to focus on peripersonal circle adjustments by keeping the goal size constant to better isolate and understand the effect of the peripersonal circle. This addressed our immediate goal of exploring system adaptations that enable players with different abilities to compete with each other.

The Three Adaptation Levels

We developed three adaptation levels: *(CI)* circle without kick button, *(CII)* circle with kick button, *(CIII)* circle with kick button and balancing model. The first two adaptation levels were directly based on our pilot observations. *CI* is meant to provide every player basic game accessibility and virtual target manipulation ability through the same peripersonal circle representation on the playfield. However, the kick button was not available and game parameters were not customized in this level. *CII* gave players using mobility aids access to the kick button to enable circle expansion and gameplay behavior similar to that of players without disabilities. Finally, *CIII* employed the game balancing model to balance players' skills and physical abilities by automatically adapting their circle size (i.e., controlling their reach advantage) based on their performance in single player pre-tests.

STUDY

To explore our system's effectiveness based on the determined three adaptation levels, we conducted a two-day user study involving six sets of three 1-on-1 matches each played with a different adaptation level.

PID	Sex/Age	Diagnosis	Mobility Aids used	Kick button Position*
P1	M, 12	Cerebral palsy	Power wheelchair	Handheld
P2	M, 12	Spina bifida	Manual wheelchair	Finger
P3	M, 14	Merosin deficient congenital muscular dystrophy	Power wheelchair	Handheld
P4	F, 14	N/A	N/A	N/A
P5	M, 16	Duchenne muscular dystrophy	Power wheelchair	Handheld
P6	F, 9	N/A	N/A	N/A
P7	M, 11	Cerebral Palsy	Manual wheelchair	Finger
P8	M, 12	Muscular dystrophy	Power wheelchair	Handheld
P9	M, 10	Spinal Muscular Atrophy	Power wheelchair	Power chair desk
P10	F, 15	Spinal Muscular Atrophy 3	Manual wheelchair	Finger
P11	F, 16	N/A	N/A	N/A
P12	M, 11	N/A	N/A	N/A

Table 2. Participant profiles showing mobility aids used and respective kick button position during playtests. *Kick button was only used in adaptation condition *CII + CIII*.

Research Questions

Our evaluation addressed four primary research questions:

Q1: *Overall, how did players perceive the nature or benefit of the game?* We were interested to understand how players perceived the overall nature of the game and system and what elements they liked most about it.

Q2: *How did players feel about presence or absence of a kick button?* We hypothesized that players using wheelchairs would feel an unfair disadvantage when playing without kick-button.

Q3: *What adaptation level did players prefer most?* We hypothesized that adaptation level *III* would be preferred.

Q4: *How did players feel about competing against people of different abilities?* We wanted to understand how players with different disabilities and mobility aids experience playing against each other in a competitive sport setting.

Participants

We recruited a total of 12 participants (8 male, 5 female) in the age range of 9 to 16 years old from a local pediatric rehabilitation center through flyers and word of mouth (see Table 2). Our primary selection criteria were that participants be between 8-17 years of age, able to see, hear, and have response capability to play and evaluate the game regardless of what mobility aid they used.

Our sample included 8 participants with mobility disabilities, 5 who used power wheelchairs for mobility and 3 who used manual wheelchairs. The remaining 4 participants did not have mobility disabilities and participated without mobility aids. Eight participants were active in sports (6 in adaptive sports). Though none mentioned hockey, game mechanics were clear to all participants. Players participated in pairs and were given the option to bring a friend or sibling to play against. However, with our sample, we were unable to produce all possible permutations of player pairs. All participants received US $20 compensation for their time.

Procedure

Participants and their parents completed assent forms and pre-study questionnaires before being introduced to *iGYM*. The introduction consisted of a brief demonstration of the peripersonal circle and the interaction (circle expansion) available within the game, as well as the rules and general concepts of the game (score; defend; do not cross the centerline). Participants competed head-to-head in three 5-minute matches, one in each adapted condition. They were not told that game parameters would be changed, only that they would play three matches against each other. The order of the adaptation levels for 1-on-1 matches were randomized using all possible permutations for different player pairs so as to avoid ordering bias.

Prior to their match in the *CIII* condition, participants completed a 4-minute round in a single-player mode. Based on their scores from this single player round, the Game Balancing Model generated system parameters to be used in the *CIII* condition. The player not participating in the single-player round used the time as a rest period and was taken to a space out of direct view of the playfield.

Data Collection

Five research team members had fixed roles during the study to maintain protocol and guide children and parents through data collection. Data was collected in four stages:

1) Pre-study questionnaire (before 1-on-1 matches)

The questionnaire consisted of 11 questions in two blocks focusing on: (A) demographics and information on disabilities, and (B) frequency and social nature of participants' physical activity and video gaming habits.

2) Observation data (during each match)

One researcher documented observation data during each match pertaining to strategy and movement on the playfield and emotions expressed during playtests (e.g. gestures or facial expressions of joy).

3) Ratings and rankings (after each match)

After each 1-on-1 match players were separated and asked to rate their level of agreement with statements about fun, fairness and competitiveness of the game on a 5-point Likert scale. After matches two and three, they were also asked which of the previous matches they preferred in order to determine preferences across the three adaptation conditions. Informed by our experience of collecting this data from children during the pilot study, we reduced cognitive load by simplifying survey questions and presenting the Likert scale using smileys on whiteboards.

4) Post-study interview (after the 3 matches)

Semi-structured interviews were used to probe earlier responses and to gather feedback on participants' experience with the system. Data from stages 1) and 2) and 3) provided context for 4) and our later analysis. Post-study interview questions included:

1. Which of the matches was your favorite? Why?
2. Which parts of the game did you enjoy most?
3. Which parts not? How would you change them?
4. How well did the circle and kick button work?
5. Your opponent was on foot and you in a wheelchair (and vice versa). Did this affect how you played?

Analysis

Survey data and match scores per adaptation level were entered into a spreadsheet as context for our analysis of interview and questionnaire responses. For instance, score data allowed us to draw parallels between match preference and performance, and observation data helped us understand player behavior while playing against people with different abilities. Likert-scale ratings from questionnaires on fun, fairness, and challenge were analyzed using median and mode. Due to low statistical power we focused on qualitative analysis. Two members of the research team independently used thematic coding to analyze questionnaire and interview data. The study team unified codes and correlated these with observations and scores from each match using affinity diagramming.

RESULTS

We present our results along with our four research questions.

Overall, how did players perceive the nature or benefit of the game?

Players drew system comparisons to soccer, hockey, and air hockey, which suggested that the system was indeed perceived as being analogous to traditional sports. One player stated, *"I liked me being the hitter thing. You know how in normal air hockey you go like that with the thing [arm motion of sliding air hockey paddle toward puck]? Well, you're actually the thing!"* (P7, player using manual wheelchair). In terms of gameplay, players described the game as fun, competitive, fast-paced, and strategic, and expressed their appreciation for these attributes. One player noted, *"I just like a challenge. I like for it to be as fair as possible."* (P3, player using power wheelchair), while another mentioned *"I liked when it gets going faster, like a volley. That's what makes regular air hockey enjoyable - the back and forth."* (P11, player without wheelchair). Further, five of the participants who used wheelchairs (P2, P3, P5, P7, P9) reported that they had prior experience with adaptive sports, and expressed appreciation for the fact that unlike other adaptive sports, *iGYM* did not require special equipment to be played adaptively, *"[In other adaptive sports] sometimes you can't reach the [ball or puck] because you're so low in a wheelchair, but [with this] that's not the case. It adapts it for you and it's easier. It's basically adapted for everyone, even people with no physical disabilities."* (P7, player using manual wheelchair).

How did players feel about presence or absence of a kick button?

Interview responses indicated that the kick button worked well as an equalizer, provided better control, and reduced wheelchair movement to an extent that the game seemed more comfortable to players, *"I noticed first I was going in circles a lot more often because I was trying to get the circle from going into my goal, then the button really helped me with these issues."* (P1, player using power wheelchair). Players stated that in presence of a kick button, they adopted the strategy of staying near their goals to prevent opponent goals and own goals, and also hitting the kick button very frequently, which they described as "spamming." Spamming was best exemplified by P5 (player using power wheelchair) who stayed inside the goalie crease for the entirety of their two-player match against P6 (player without wheelchair). By spamming the kick button, P5 covered their goal almost completely, and P6 seemed discouraged due to lack of goals scored.

What adaptation level did players prefer most?

CIII was the most preferred adaptation level for 5 out of 12 players (P3, P5, P10, P11, P12) due to higher perceived fairness and competitiveness. Four of them (P5, P10, P11, P12) specifically noted small score differentials as an indicator of fairness, and suggested preference towards matches that gave both opponents an equal chance of winning, "*[CIII] felt like the most fair and competitive. The first [match, in condition CII] we could do offensive things but we hadn't really figured out defense, and every time we tried to defend we would just score on ourselves. Then the middle game [CIII] we were able to like actually both attack and defend, and then in the last game [CI] she was pretty much only able to defend.*" (P11, player without wheelchair). This was also reflected in actual score differentials produced in that condition, which were the lowest out of all three adaptation levels for 4 out of 6 player pairs (2 ties and 2 matches with a 3-goal score differential) (see Table 3). Interview responses suggest that players noticed whether they won or lost in each match, but winning or losing did not seem to have a strong effect on preference for the adaptation level. "Blowout" matches with large score differentials were not preferred by any participant due to lower perceived fairness.

Player Pairs		Preferred level	CI Scores, CII Scores, CIII Scores	Score differential	Minimum score differential
P-M	P1 (P)	*CII* (L)	10-14, 17-23, 14-28	4 6 14	*CI*
	P2 (M)	*CI* (W)			
P-N	P3 (P)	*CIII* (W)	9-13, 15-6, 11-8	4 9 3	*CIII*
	P4 (N)	*CII* (L)			
P-N	P5 (P)	*CIII* (T)	12-10, 12-12, 29-9	2 20 0	*CIII*
	P6 (N)	*CI* (L)			
M-P	P7 (M)	*CII* (L)	14-12, 13-16, 12-22	2 3 10	*CI*
	P8 (P)	*CI* (L)			
P-N	P9 (P)	*CII* (W)	4-15, 7-3, 7-10	11 4 3	*CIII*
	P12 (N)	*CIII* (W)			
M-N	P10 (M)	*CIII* (T)	8-17, 20-14, 15-15	9 6 0	*CIII*
	P11 (N)	*CIII (T)*			

Legend

Win (W)	Players using power wheelchairs (P)
Tie (T)	Players using manual wheelchairs (M)
Loss (L)	Players without disability (N)

Table 3. Overall preferred adaptation level and score differentials for participants.

In terms of overall preference, adaptation level *CIII* was closely followed by *CII* (chosen by 4 out of 12 players). The perceived fun and fairness scores were similar between adaptation levels *CI* and *CIII* for participants, with equal median and mode values for fun (median = 5, mode = 5) and fairness (median = 4.5, mode = 5), which were higher than those for *CII*. Players were, however, split regarding opinions about the fairness of adaptation level *CI*. While some participants liked the challenge and strategic gameplay that was required for playing without a kick button, others deemed it to be highly unfair for the player using a wheelchair.

How did players feel about competing against people with different abilities?

Players liked that *iGYM* allowed them to play with people of different abilities, *"I liked the fact that it was a competition. I'm very competitive, and most sports, being in a wheelchair, I can't do with other kids because my wheelchair restricts my mobility."* (P1, power wheelchair user). Most players said they had not often engaged in physical activities with people of different mobilities prior to this study. Regardless of whether or not they had a mobility disability, most initially said mobility differences did not affect their strategy or approach to the game.

On further probing, some participants described making what we recognize as internal adjustments to achieve fairness in the game, *"I feel like playing against anyone I would try to adapt my skill level to theirs. I was making sure that sometimes she was able to score and not necessarily being as offensive as I could have been."* (P11, non- wheelchair user). This was also exemplified in the P9 vs. P12 match when it was observed that P12 would wait to kick the puck until P9, a power wheelchair user, was facing forward. Additionally, P4 played with their hands in their pockets and did not utilize the circle effectively. When questioned about this adjustment, P4 stated that no adjustments were made, but observations indicate that P4's nonchalant playing style likely affected the score differential.

DISCUSSION

iGYM was designed to enable co-located play in an inclusive traditional sport setting. The pilot study showed the system was accessible to people using wheelchairs. Target speed calibration risked disrupting the game flow and had little effect on the playability (i.e. the ability to score and defend goals) compared to adaptations related to the peripersonal circle size and kick button. A subsequent study then used three adaptation levels to study the effects in isolation, assessing the performance and experience of players with different abilities and mobility aids in 1-on-1 competitions. In this section, we discuss the findings of our system adaptation efforts in the context of inclusive play and address the larger implications of designing an interactive system for inclusive play in traditional sport settings.

The Nature of the Game and Perception of Inclusive Play

Overall, players perceived the game as being a competitive, fun, and inclusive sport activity. Most notable was how players, particularly wheelchair users, expressed their perception of the game as being physical, inclusive, and adapted even for people without physical disabilities. In other words, the system was seen as enabling a "non-disability specific" play activity. A similar perspective was expressed by five other players, all wheelchair users, who made system comparisons to adaptive sports. Some indicated that adapting equipment for players with disabilities can lead to exclusion of non-disabled players. This finding indicates that adaptation measures can potentially be seen as barriers to inclusive play. Further, it does seem to validate our initial design goal of providing an adapted sport experience similar to wheelchair sports, but in an inclusive setting allowing peers without disabilities to equally participate and enjoy the game.

The Kick Button Effect

The availability of a kick button was a deciding factor for most players' perceptions of fun and fairness, and it helped to minimize score differences. It seemed to have a strong effect on the game play and game behavior of players using wheelchairs, which was noticed both by players who used a kick button and their opponents without one. Activating the kick button increased not only the peripersonal circle size commonly used to defend a goal, but also the puck speed. It had a visible, "empowering effect" that can perhaps be best compared with a "powerful" kick in soccer, where power is a key measure for the kicking success [34]. As a result, the kick button was a clearly preferred design feature for most players. However, not having a kick button promoted more active movement of wheelchair users, which was considered more challenging. For this reason, it seemed to be the preferred condition of several players who were not necessarily seeking *the* fairest game, but just *a* fairer game that provided the right challenge for them. This finding supports the importance of paying particular attention to person-centered [28] or internal [1] adjustment preferences when designing or providing interactive adaptation measures in a sport setting.

The Peripersonal Circle Interaction Quality

The quality of the peripersonal circle interaction appeared to be threefold: First, it provided each player the same peripersonal space boundary representation on the playfield (i.e., the same visible adaptation mechanism). Second, it provided each player a very similar input modality (i.e., a circle that can only travel, expand or contract; the expansion being incremental and non-incremental as the only difference). Third, individual circle size adjustments effectively compensated for response time differences due to movement restrictions of wheelchair players.

Adaptation Level Preferences

The three adaptation levels, *CI*, *CII*, and *CIII*, provided three peripersonal circle interaction versions, which helped to isolate the effects of the kick button and balancing model and in return indicated different qualities and benefits of each adaptation level. Overall findings suggest that: *CI* made the game more accessible, *CII* more playable, and *CIII* more balanced. The sample size, however, is too small to make generalizations beyond an overall preference for the matches using the kick button (*CII+CIII).* Further, some "blowouts" matches might have resulted from a limitation of our current balancing model (CIII) that does not work well when the player's play-style changes over time within or after the training session. For example, some players did not play well in the beginning but got more accustomed as the 4-minute training continued while the level of difficulty increased. This could have led to cases where the system underestimated the player's performance for the parameters tested in the earlier training and overcompensates by providing easy parameters for that player in 1-on-1s.

Most surprising was the preference of a few players using wheelchairs towards *CI*, which was the least adapted level, lacking both the kick button and balancing model. We think this preference implies that *CI* with the peripersonal circle adaptation alone is in fact already accommodating many ability differences that can typically result from wheelchairs' movement restrictions, such as side-turns, which might affect player experience. Such movement restrictions and the need to address them in direct competitions with players without disabilities are also discussed by Gerling [17] as a key challenge for "accommodating extreme ability differences." This finding suggests the importance of equally accessible and very functionally similar input modalities to level the playing field in sport settings. Preference of a particular adaptation level might also be indicative of individual differences such as inherent competitiveness, which might bias player preference toward a more difficult or easier condition. This could be accommodated in real world applications by providing the option of playing with or without a kick button.

Competition Among People with Different Abilities

The notion of fairness in an inclusive competitive play setting was particularly interesting to explore. Perceptions of unfairness were observed regardless of whether a mobility aid was being used. P8, a power chair user, mentioned, *"The other games [CII, CIII] didn't seem as fair. It was about me being in a power chair and he was not, I have the advantage in that case."* (P8, player using power wheelchair). In other words, in some cases our system appeared over-balanced for wheelchair users and in other cases for players without wheelchairs. This might imply that the system design was not perceived as an advantage for either player group. Further, it could imply that notions of fairness are also informed by individual attributes such player competitiveness or cooperativeness. Marker et al. [37] highlight both cooperation and competition as key aspects that impact player motivation and behavior, which have yet to be examined more in social exergame interventions.

LIMITATIONS AND FUTURE WORK

Individual player preferences and social factors such as cheering spectators (friends or family members), playing against a friend or family member, and the effects of internal balancing by some players to ensure fairness may have affected gameplay. However, since these moderating factors were not the focus of our investigation, we did not explicitly control for them. Further, we conducted the study without running a competition with ranking or incentives for winning. A more stringent, competitive atmosphere might highlight different aspects of the gameplay that were undetectable in the current study design.

While the formal study design was necessary to isolate effects, it limited the ways in which players could engage with *iGYM*. After the study sessions, participants were given extra time to play without restrictions on the number of players on the field or added pressure of observation. This seemed to modify the gameplay. It prompted multiplayer matches, participation using mobility aids other than wheelchairs (such as crutches), and children playing with their parents. These observations introduced interesting new dimensions of unrestricted play that we plan to further explore through a "play day", where players will be invited to participate in open play sessions.

Our study focused on inclusive play for children because of the potential developmental benefits to this age group, for which social and physical barriers are often experienced on a daily basis. That said, the system design could be extended to adults and more than two players. Our future design goal is to further develop the system for multiplayer games on a larger scale.

On a technical level, our current implementation uses a user-specific but static parameter set for adapting game mechanics after a pre-test. We want to develop a version that continually adapts game mechanics even during the game. This is in principle possible by reinforcement learning based parameter tuning that treats recent game segments as pre-tests.

On a theoretical level the literature on peripersonal space as it relates to exergames and accessibility concerns is largely unexplored. Mueller et al.'s framework for designing exergames [39] might help to connect this literature with further research on designing inclusive exergames. Adding to this framework, we suggest introducing the lens of the "intermediate body" for the subjectively experienced virtual body that players access in the form of our peripersonal circle or other forms of peripersonal space boundary simulations.

CONCLUSION

We have presented a prototype of an interactive floor projection system designed to enable co-located physical play experiences for people with and without mobility disabilities. Playtests exploring three different adaptation levels showed that our peripersonal circle interaction and kick-button feature were key to achieving system accessibility and playability of a fast-paced game. Findings suggest most players, regardless of mobility aid, preferred matches in which the kick button enhanced the playability for the player using a wheelchair (*CII+CIII)* over matches without the kick button (*CI*). Preferences, however, were multifactorial and also based on players desire to challenge themselves, and perceptions of fairness were often formed regardless of whether players were using wheelchairs or not. Our design features and related findings have theoretical and practical implications for creating novel, inclusive exergame opportunities in traditional sport settings.

ACKNOWLEDGEMENTS

We thank our playtest participants; Betsy Howell for help with recruitment and consulting; Sun Young Park, Priyanka Raju, and Emma Shpiz for contributions to earlier project development and study; Yaqian Zhao and Luyao Gong for technical development; and the reviewers for manuscript improvement suggestions. The iGYM project is funded by the U-M Exercise & Sport Science Initiative.

REFERENCES

[1] David Altimira, Florian “Flyod” Mueller, Gun Lee, Jenny Clarke & Mark Billinghurst. 2014. Towards understanding balancing in exertion games. In *The conference on advances in computer entertainment technology*, 1-8. https://dx.doi.org/10.1145/2663806.2663838

[2] ASBGlassFloor. 2019. LED Floor Virtual Air Hockey Face Off. Video. (11 Feb 2019.). Retrieved April 8, 2019 from https://www.youtube.com/watch?v=xFyYA5QGbxE

[3] Michela Bassolino, Andrea Serino, Silvia Ubaldi, and Elisabetta Làdavas. 2010. Everyday use of the computer mouse extends peripersonal space representation. *Neuropsychologia* 48, 3: 803–811. https://doi.org/10.1016/j.neuropsychologia.2009.11.009

[4] Monica Biggio, Ambra Bisio, Laura Avanzino, Piero Ruggeri, and Marco Bove. 2017. This racket is not mine: The influence of the tool-use on peripersonal space. *Neuropsychologia* 103: 54–58. https://doi.org/10.1016/j.neuropsychologia.2017.07.018

[5] Steve Blank, Jerry Engel, Jim Hornthal. 2014. *LeanLaunchPad. Evidence-Based Entrepreneurhip* Educators Guide 6th Edition.

[6] Patrick Carrington, Amy Hurst, and Shaun K. Kane. 2014. Wearables and chairables: inclusive design of mobile input and output techniques for power wheelchair users. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '14). ACM, New York, NY, USA, 3103-3112. https://dx.doi.org/10.1145/2556288.2557237

[7] Jared Cechanowicz, Carl Gutwin, Scott Bateman, Regan L. Mandryk & Ian Stavness. 2014. Improving player balancing in racing games. In *Proceedings of the first ACM SIGCHI annual symposium on computer-human interaction in play* (CHI ’14). 47-56. http://dx.doi.org/10.1145/2658537.2658701

[8] Franceli L. Cibrian, Monica Tentori & Ana I. Martínez-García. 2016. Hunting Relics: A Persuasive Exergame to Promote Collective Exercise in Young Children. In *International Journal of Human–Computer Interaction*, 32:3, 277-294. https://doi.org/10.1080/10447318.2016.1136180

[9] Rory A. Cooper, Arthur Jason De Luigi. 2014. Adaptive Sports Technology and Biomechanics: Wheelchairs. In *Paralympic Sports Medicine and Science* Vol. 6 Iss. 8S1 (2014). S31-S39. https://dx.doi.org/10.1016/j.pmrj.2014.05.020

[10] Mihaly Csikszentmihalyi. 1990. *Flow: The psychology of optimal experience*. New York: Harper & Row.

[11] Stephen Cuzzort and Thad Starner. 2008. AstroWheelie: A wheelchair-based exercise game. In *Proceedings of the 2008 12th IEEE International Symposium on Wearable Computers* (ISWC '08). IEEE Computer Society, Washington, DC, USA, 113-114. https://doi.org/10.1109/ISWC.2008.4911599

[12] Robby van Delden, Alejandro Moreno, Ronald Poppe, Dennis Reidsma, and Dirk Heylen. 2017. A Thing of Beauty: Steering Behavior in an Interactive Playground. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (CHI '17). ACM, New York, NY, USA, 2462-2472. https://doi.org/10.1145/3025453.3025816

[13] Robby van Delden, Steven Gerritsen, Dirk Heylen, Dennis Reidsma. 2018. Co-located augmented play-spaces: past, present, and perspectives. In *Journal on Multimodal User Interfaces* (2018) 12: 225. https://doi.org/10.1007/s12193-018-0269-z

[14] Ansgar E. Depping, Regan L. Mandryk, Chengzhao Li, Carl Gutwin & Rodrigo Vicencio-Moreira. 2016. How disclosing skill assistance affects play experience in a multiplayer first-person shooter game. In *Proceedings of the 2016 CHI conference on human factors in computing systems* (CHI ’16). 3462-3472. https://dx.doi.org/10.1145/2858036.2858156

[15] Jamal K. Edey, Katie Seaborn, Carmen Branje, Deborah I. Fels. 2014. Powered to Play: A mixed reality game for people driving powered chairs. In *IEEE Games Media Entertainment*. https://doi.org/10.1109/GEM.2014.7048101

[16] Giulia Galli, Jean Paul Noel, Elisa Canzoneri, Olaf Blanke, Andrea Serino. 2015. The wheelchair as a full-body tool extending the peripersonal space. In *Frontiers in Psychology*, *6*, 639. https://doi.org/10.3389/fpsyg.2015.00639

[17] Kathrin Maria Gerling, Matthew Miller, Regan L. Mandryk, Max Valentin Birk, and Jan David Smeddinck. 2014. Effects of balancing for physical abilities on player performance, experience and self-esteem in exergames. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '14). ACM, New York, NY, USA, 2201-2210. https://doi.org/10.1145/2556288.2556963

[18] Kathrin Gerling, Kieran Hicks, Michael Kalyn, Adam Evans, and Conor Linehan. 2016. Designing Movement-based Play With Young People Using Powered Wheelchairs. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (CHI '16). ACM, New York, NY, USA, 4447-4458. https://doi.org/10.1145/2858036.2858070

[19] Roland Graf, Sun Young Park, Emma Shpiz & Hun Seok Kim. 2019. In *Proceedings of the Extended Abstracts in Computer-Human Interaction* (CHI’ 19).

ACM, Glasgow, Scotland, 1-9. https://doi.org/10.1145/3290607.3312792

[20] Kaj Grønbæk, Ole S. Iversen, Karen Johanne Kortbek, Kaspar Rosengreen Nielsen, and Louise Aagaard. 2007. IGameFloor: a platform for co-located collaborative games. In *Proceedings of the international conference on Advances in computer entertainment technology* (ACE '07). ACM, New York, NY, USA, 64-71. https://dx.doi.org/10.1145/1255047.1255061

[21] Kristin Guðmundsdóttir, Astrid Lilja Wille, Alexandru Savu. 2013. *Designing Games for Children with Cerebral Palsy*. In Schouten B., Fedtke S., Bekker T., Schijven M., Gekker A. (eds) *Games for Health. Springer Vieweg, Wiesbaden.* https://doi.org/10.1007/978-3-658-02897-8_8

[22] Joan Mora-Guiard, Ciera Crowell, Narcis Pares, Pamela Heaton. 2017. Sparking social initiation behaviors in children with Autism through full-body Interaction. In *International Journal of Child-Computer Interaction*, Volume 11, 2017, Pages 62-71. https://doi.org/10.1016/j.ijcci.2016.10.006

[23] Hamilton A. Hernandez, T.C. Nicholas Graham, Darcy Fehlings, Lauren Switzer, Zi Ye, Quentin Bellay, Md Ameer Hamza, Cheryl Savery, and Tadeusz Stach. 2012. Design of an exergaming station for children with cerebral palsy. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '12). ACM, New York, NY, USA, 2619-2628. https://doi.org/10.1145/2207676.2208652

[24] Hamilton A. Hernandez, Zi Ye, T.C. Nicholas Graham, Darcy Fehlings, and Lauren Switzer. 2013. Designing action-based exergames for children with cerebral palsy. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '13). ACM, New York, NY, USA, 1261-1270. https://doi.org/10.1145/2470654.2466164

[25] Nicholas P. Holmes, Charles Spence. 2004. The body schema and multisensory representation(s) of peripersonal space. In *Cognitive Processing*, Vol 5, Issue 2, (June 2004), 94-105. https://doi.org/10.1007/s10339-004-0013-3

[26] Susan Hwang, Adrian L. Jessup Schneider, Daniel Clarke, Alexander MacIntosh, Lauren Switzer, Darcy Fehlings & T.C. Nicholas Graham. 2017. How game balancing affects play: player adaptation in an exergame for children with cerebral palsy. In *Proceedings of the 2017 conference on designing interactive systems* (DIS '17). 699-710. https://dx.doi.org/10.1145/3064663.3064664

[27] Katherine Isbister. 2010. Enabling Social Play: A Framework for Design and Evaluation. In *Bernhaupt R. (eds) Evaluating User Experience in Games. Human-Computer Interaction Series*. Springer, London. https://doi.org/10.1007/978-1-84882-963-3_2

[28] Susan A. Jackson, Mihaly Csikszentmihalyi. 1999. *Flow in sports: the keys to optimal experiences and performances.* Human Kinetics.

[29] Michael S. Jeffress, William J. Brown. 2017. Opportunities and Benefits for Powerchair Users Through Power Soccer. In *Adapted Physical Activity Quarterly*, 2017, 34, 235-255. https://doi.org/10.1123/apaq.2016-0022

[30] Mads Møller Jensen and Kaj Grønbæk. 2016. Design Strategies for Balancing Exertion Games: A Study of Three Approaches. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems* (DIS '16). ACM, New York, NY, USA, 936-946. https://doi.org/10.1145/2901790.2901843

[31] Eleftherios Kellis, Athanasios Katis. 2007. Biomechanics and determinants of instep soccer. In *Journal of Sports Science & Medicine*. 6. 154-65. https://www.jssm.org/hf.php?id=jssm-06-154.xml

[32] Gillian King, Theresa Petrenchik, Mary Law & Patricia Hurley. 2009. The Enjoyment of Formal and Informal Recreation and Leisure Activities: A comparison of school-aged children with and without physical disabilities. In *International Journal of Disability, Development and Education*, 56:2, 109-130. https://doi.org/10.1080/10349120902868558

[33] Peter Gall Krogh, Martin Ludvigsen, Andreas Lykke-Olesen. 2004. Help me pull that cursor - A Collaborative Interactive Floor Enhancing Community Interaction. In *proceedings of OZCHI 2004, 22-24 November, 2004 at the University of Wollongong, Australia.* ISBN:1 74128 079. https://kollision.dk/pdf/ozchi2004.pdf

[34] Adrian Lees & Lee Nolan. 1998., The biomechanics of soccer: A review. In *Journal of Sports Sciences*, 16:3, 211-234. https://doi.org/10.1080/026404198366740

[35] Laurie A. Malone, Jennifer L. Rowland, Rebecca Roger, et al. 2016. Active videogaming in youth with physical disability: gameplay and enjoyment. In *Games Health Journal*. 2016 Oct 03. https://doi.org/10.1089/g4h.2015.0105

[36] Dan Margalit, Joseph Rabinoff. 2018. *Interactive Linear Algebra.* Georgia Institute of Technology.

[37] Arwen M. Marker and Amanda E. Staiano. 2015. Better Together: Outcomes of Cooperation Versus Competition in Social Exergaming. In *Games for Health Journal* 4, 1: 25–30. https://doi.org/10.1089/g4h.2014.0066

[38] Michelle Miller, Ellen S. Kaitz. 2015. *Adaptive Sports and Recreation.* In: Michael A. Alexander, Dennis J. Matthews. (2015). *Pediatric Rehabilitation Principles*

and Practice. Fifth Edition. Chapter 9. Demos Medical Publishing, 196-216.

[39] Cheryl Missiuna, Nancy Pollock. 1991. Play Deprivation in Children With Physical Disabilities: The Role of the Occupational Therapist in Preventing Secondary Disability. In *American Journal of Occupational Therapy*, 1991; Vol 45(10):882-888. https://doi.org/10.5014/ajot.45.10.882

[40] Florian 'Floyd' Mueller, Darren Edge, Frank Vetere, Martin R. Gibbs, Stefan Agamanolis, Bert Bongers, and Jennifer G. Sheridan. 2011. Designing sports: a framework for exertion games. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '11). ACM, New York, NY, USA, 2651-2660. https://doi.org/10.1145/1978942.1979330

[41] Jörg Müller, Dieter Eberle, and Constantin Schmidt. 2015. BaseLase: An Interactive Focus+Context Laser Floor. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (CHI '15). ACM, New York, NY, USA, 3869-3878. https://doi.org/10.1145/2702123.2702246

[42] Jean-Paul Noel, Christian Pfeiffer, Olaf Blanke, Andrea Serino. 2015. Peripersonal space as the space of the bodily self. In *Cognition, 144,* 49-57. http://dx.doi.org/10.1016/j.cognition.2015.07.012

[43] Jesse Schell. 2008. *The Art of Game Design: A Book of Lenses*. P 438. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA.

[44] Elena Marquez Segura, Katherine Isbister. 2015. Enabling Co-Located Physical Social Play: A Framework for Design and Evaluation. In *Bernhaupt R. (eds) Game User Experience Evaluation. Human–Computer Interaction Series.* Springer, Cham https://doi.org/10.1007/978-3-319-15985-0_10

[45] Abbie Solish, Adrienne Perry, Patricia Minnes. 2010. Participation of Children with and without Disabilities in Social, Recreational and Leisure Activities. In J*ournal of Applied Research in Intellectual Disabilities,* 23: 226-236. https://doi.org/10.1111/j.1468-3148.2009.00525.x

[46] Issey Takahashi, Mika Oki, Baptiste Bourreau, Itaru Kitahara, Kenji Suzuki. 2018. FUTUREGYM: A gymnasium with interactive floor projection for children with special needs. In *International Journal of Child-Computer Interaction*, Vol 15, 2018, 37-47. https://doi.org/10.1016/j.ijcci.2017.12.002

[47] Peta Wyeth, Jennifer Summerville, and Barbara Adkins. 2011. Stomp: an interactive platform for people with intellectual disabilities. In *Proceedings of the 8th International Conference on Advances in Computer Entertainment Technology* (ACE '11). ACM, New York, NY, USA, Article 51, 8 pages. https://doi.org/10.1145/2071423.2071487