iGYM: A Wheelchair-Accessible Interactive Floor Projection System for Co-located Physical Play

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ABSTRACT

Physical play opportunities for people with motor disabilities typically do not include co-located play with peers without disabilities in traditional sport settings. In this paper, we present a prototype of a wheelchair-accessible interactive floor projection system, iGYM, designed to enable people with motor disabilities to compete on par with, and in the same environment as, peers without disabilities. iGYM provides two key system features—peripersonal circle interaction and adjustable game mechanic (physics)—that enable individualized game calibration and wheelchair-accessible manipulation of virtual targets on the floor. Preliminary findings from our pilot study with people with motor disabilities using power wheelchairs, manual wheelchairs, and people without disabilities showed that the prototype system was accessible for all participants at higher than anticipated target speeds.

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KEYWORDS

Adaptive sport; interactive floor; co-located play; peripersonal space; game accessibility

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 push button – to manipulate a virtual target on the floor.

Our work has implications for designing novel, physical play opportunities in inclusive traditional sport settings.

1 INTRODUCTION

People with motor disabilities have limited access to physical play opportunities with their peers without disabilities particularly in traditional sport settings such as school and community-based sport or recreation facilities due to physical and social barriers [12]. Further, they are at a greater risk for developing serious health problems and secondary health conditions, such as pain, fatigue, depression and obesity, as a result of physical inactivity [14].

In this paper, we present a prototype of a wheelchair-accessible interactive floor projection system, iGYM, designed to facilitate co-located play and exercise activities for people of all abilities. Two key design features of this system are the peripersonal circle interaction and adjustable game mechanic (physics) that allow people with different abilities and mobility aids to engage in realistic manipulation of virtual targets on an interactive floor (see Fig. 1).

To explore the system accessibility for co-located play in a traditional sport setting, we developed an air hockey inspired game for two players. Preliminary findings of a pilot study with 9 participants, including people with motor disabilities using power wheelchairs, manual wheelchairs, and people without disabilities, showed the system was accessible for all participants at higher than anticipated target speeds.

2 RELATED RESEARCH

Adaptive sports such as 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 [9]. However, adaptive sports typically don't address the physical and social barriers [12] that limit the opportunities particularly for young people with motor disabilities to engage in physical play activities with their non-disabled peers [10].

Exergames for people with motor disabilities often rely on screen-based platforms (e.g. Nintendo Wii or Xbox Kinect), which are impractical for co-located play scenarios [15] similar to adaptive sports or sport activities in general. A sub-category of exergames for players with disabilities are wheelchair-based movement games [4, 6] in which the wheelchair movement and position becomes part of the element that controls the game. 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. This game allows explicit and hidden balancing approaches to accommodate players' different skills and abilities in a screen-based setting [7].

Most related to iGYM's spatial and technical configuration are interactive floor systems. The potential of interactive floors to facilitate whole-body interactions and co-located games has been studied mostly for people with cognitive disabilities [16] or people without disabilities [3]. Further, many interactive floor systems have been deployed commercially, but no system has been developed yet for people with motor disabilities in inclusive traditional sport settings.

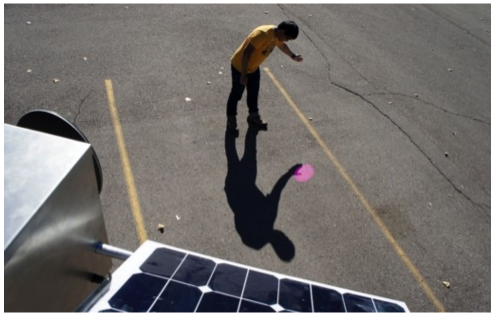

Figure 2: Solar Pink Pong player using his shadow to interact with animated pink sunlight reflection on the street.

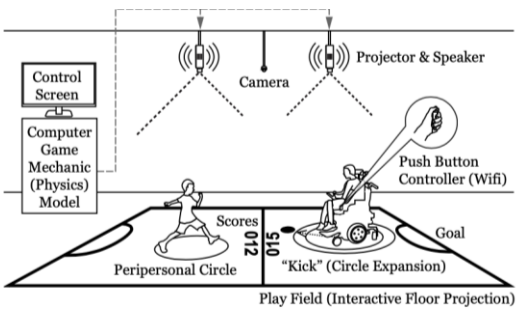

Figure 3: iGYM's spatial and technical configuration. Players' peripersonal circle can be expanded to "kick" a target on the interactive floor by limb movement or push-button activation.

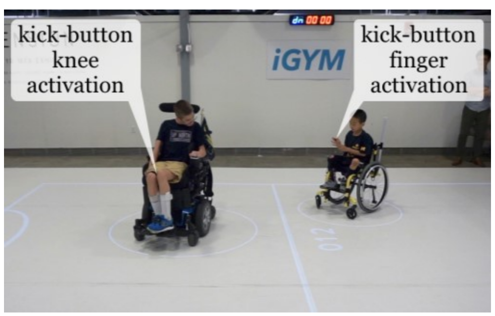

Figure 4: Two examples of push button activation; knee (left player) and index finger (right player).

3 THE iGYM SYSTEM

3.1 Design and Development Process

To develop iGYM, we followed an iterative design process that built on Graf et al.'s [8] prior work on the interactive art installation Solar Pink Pong (see Fig. 2). One of iGYM's key design features, the peripersonal circle interaction, was inspired by observing how Solar Pink Pong players in public naturally interacted with a projected target on the ground using both their bodies and shadows. Based on our observation of these body-shadow interactions, we designed the peripersonal circle by developing a responsive circle that augments both the player's body and target manipulation ability. We then framed the circle interaction in reference to literature on peripersonal space boundary modulations [1, 5].

During our design and development process from low to high fidelity prototypes, we received feedback from informal interviews with health professionals in a customer discovery program and casual observation of a few physical therapy sessions of people with motor disabilities.

3.2 Spatial and Technical Configuration

The iGYM prototype has been implemented in a large common space with ceiling heights (6.8m) and light levels (~270 lux) similar to those of a school gym. Two ceiling mounted projectors with integrated loudspeakers create a 6.3 x 4.2 m large projection area on the floor (see Fig. 3). A ceiling mounted camera monitors the players' movements. It captures graphic frames and streams them to the host computer. The system output is reduced to minimal visual projections on the floor enhanced by some sound effects.

3.3 Peripersonal Circle Interaction and Adjustable Game Mechanic (Physics)

iGYM projects a circle on the floor around each detected player that enters the playfield. The circle's center travels, and the perimeter expands or contracts based on the player's bodily movements (e.g. arm or feet movements) representing the peripersonal space boundary. The responsive circle can be used to directly manipulate (e.g. "kick") a virtual target.

Likewise, a player using a wheelchair can use a wireless push button controller to expand their peripersonal circle representation and achieve the same effect. The push button controller can be attached to the body (e.g. hand, finger, torso, or leg mounted) or mobility aid (see Fig. 4). Our current controller prototype is a modified Bluetooth wireless mouse that allows plugging in switches with different form factors.

In addition, iGYM has adjustable game mechanic (physics) model parameters that allow realistic and fast-paced interaction with a virtual target on the floor. This feature also allows balancing players' individual differences in response time or processing speed by enabling game mechanic parameter calibration customized 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 can score and defend goals similar to playing air hockey or soccer.

Table 1: Key parameters for game calibration.

Global Parameters	**Default***	**Max**
Target diameter (m)	0.36	0.94
Individual Parameters for each Player & Playfield side		
Min target speed (m/s)	0.1	0.9
Max target speed (m/s)	11.5	13.8
Goal size for scoring (m)	2.8	4.2
Playfield friction (m/s^2)	0.25	1.7
Playfield boundary elasticity for contact with target (%)	100	100
Peripersonal circle boundary elasticity for contact with target**	100	100
Individual Parameter for Push Button Controller		
Max diameter of peripersonal circle when expanded (m)	3.2	4.2
Max Speed of peripersonal circle expansion (m/s)	20	20
Max hold time of expanded peripersonal circle (s)	3.1	3.1

*Parameter baseline used in most pilot playtests. **The speed changes to a percentage of the original.

4 PILOT STUDY

4.1 Participants and Procedure

To evaluate iGYM's feasibility for co-located play in an inclusive traditional sport setting, we invited 9 participants (2 female) between 7 and 19 years old, including 7 people with motor disabilities (5 power wheelchair users, 2 manual wheelchair users) and 2 players without disabilities for a pilot study. At this stage, we were mainly interested in evaluating the system's robustness and accessibility as well as finding and determining an appropriate speed of the game to make it fair for all participants.

Playtests were conducted across three separate days. Players were paired up to compete against each other in several 10min long playtest sessions and five categories to test all player pair constellations with two frequently used mobility aids (see Table 2). The game parameters were chosen individually for each player during a "warm-up" phase before the game started. During this phase, the preferred mounting position and form factor of the "kick-button" was also determined in consultation with players.

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

4.2 Preliminary Findings

The preliminary results of the pilot study show that iGYM's air hockey game was accessible and enjoyable for all participants at higher than anticipated target speeds. The maximum target speed parameters were overall in a relatively close range (approximately 11.5-13.8m/s) at the system's currently implemented upper speed limit (13.8m/s), which is about five times higher than the target speed in the art installation Solar Pink Pong (2.5m/s) that initially inspired iGYM.

The peripersonal circle interaction feature was accessible and intuitive to use for all players if the target was in front of the players; it was less intuitive to use particularly for wheelchair users if the target was behind their back. Two different switch form factors (i.e. 2.5cm and 3.5cm activation surface) and mounting positions (i.e. hands and legs/knees) of the "kick-button" accommodated all our participants using wheelchairs. The click and hold function of the "kick-button" enabled wheelchair users to perform similar gameplay behavior as their non-disabled peers. For example, it enabled player to push the button for a kick or hold it down to keep the peripersonal circle expanded to block an opponent's kick or defend the goal. Three participants highlighted independently the push button controller and the peripersonal circle feature as their *"favorite parts"* (P1, player using power wheelchair) and the elements that make the game *"fair"* (P2, player using power wheelchair; P4, player without disability). The adjustable game mechanic (physics) model created a realistic air hockey inspired game experience and helped to set its overall pace (e.g. by adjusting the target speed, playfield friction, playfield boundary elasticity). However, using

Table 2: Five playtest categories in which players were matched up.

Player using manual wheelchair	vs.	Player using manual wheelchair
Player using power wheelchair	vs.	Player using power wheelchair
Player using power wheelchair	vs.	Player using manual wheelchair
Player using power wheelchair	vs.	Player without disability
Player using manual wheelchair	vs.	Player without disability

it for speed calibration to adapt the game for each player or playfield side individually was less practical as it risked disrupting the game's flow. Further, speed parameter adjustments seemed less significant as a potential player balancing approach compared to the effects of adjusting, for example, the size of the peripersonal circle or goal or when players changed their gameplay behavior in presence of cheering spectators or in response to their opponent's performance.

5 DISCUSSION AND FUTURE WORK

Our preliminary findings indicate the potential of iGYM's peripersonal circle for wheelchair-accessible, fast-paced manipulation of virtual targets in inclusive traditional sport settings. The general significance of the target speed in this setting is that it defines the pace of a game and a player's performance. In soccer, for example, the ball speed is associated with a powerful kick and a key measure of kicking success [11]. However, our findings also indicate the need to address the risk of accidently manipulating the target behind the player's back particularly for wheelchair users. One solution might be to provide more instructions or player coaching prior to gameplay.

Some of the social factors (i.e. cheering spectators, user balancing) that affected player engagement and performance in our pilot study seem particularly relevant for further exploration. They characterize the potential quality of the experience that our proposed system can provide in inclusive traditional sport settings.

As a next step, we plan to explore how different balancing strategies using the peripersonal circle interaction and adjustable game mechanic parameters can best enhance player experience (e.g. the perception of fairness) and performance in one-on-one competitions.

On a technical level, our future development goals are: tracking the player ID to enable multiplayer games with more than two players; the full integration of the push button controller as a wearable and chairable input device [2], for example, as a switch in power wheelchair joysticks; exploring additional games and sound designs; and, developing a floor-projected user interface that enables players to select games or change parameters by themselves.

On a theoretical level largely unexplored is the literature on peripersonal space as it relates to exergames and accessibility concerns. Mueller et al.'s framework for designing exergames [13] 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 player access in the form of our peripersonal circle or other forms of peripersonal space boundary simulations.

6 CONCLUSION

We have presented a prototype of a novel interactive floor projection system designed to enable co-located physical play for people with motor disabilities and their peers without disabilities. Preliminary results of our pilot study indicate the peripersonal circle feature provided all players access and similar and fast target manipulation opportunities regardless of what type of, or if, a mobility aid was used. Our work has theoretical and practical implications that can help designers develop novel, co-located physical play opportunities in inclusive traditional sport settings.

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