Designing Action-based Exergames for Children with Cerebral Palsy

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ABSTRACT

Children with cerebral palsy (CP) want to play fast-paced action-oriented videogames similar to those played by their peers without motor disabilities. This is particularly true of *exergames,* whose physically-active gameplay matches the fast pace of action games. But disabilities resulting from CP can make it difficult to play action games. Guidelines for developing games for people with motor disabilities steer away from high-paced action, including recommendations to avoid the need for time-sensitive actions and to keep game pace slow. Through a year-long participatory design process with children with CP, we have discovered that it is in fact possible to develop action-oriented exergames for children with CP at level III on the Gross Motor Function Classification Scale. We followed up the design process with an eight-week home trial, in which we found the games to be playable and enjoyable. In this paper, we discuss the design of these games, and present a set of design recommendations for how to achieve both action-orientation and playability.

ACM Classification Keywords

H.5.2 [Information Interfaces And Presentation]: User Interfaces - User-centered design; K.4.2 [Computers And Society]: Social Issues - Assistive technologies for persons with disabilities;

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Exergame; video game design; children with cerebral palsy.

General Terms

Human Factors, Design.

INTRODUCTION

Cerebral palsy (CP) is a group of disorders that affect motor function. Children with CP who need a mobility aid to walk (those classified as level III in the Gross Motor Function Classification System (GMFCS)[12]) show a significant functional decline as they grow into adulthood. This loss of motor function is caused by multiple factors such as proximal muscle weakness resulting from disuse, poor physical fitness, and changes in body composition [12].

Exergames, video games that involve vigorous physical activity, represent a promising way for children with CP to get the exercise they need to break this cycle of deconditioning. Exergames have been used to motivate patients with CP to do physical therapy, allowing improvements in range of motion [4], balance [5], and physical fitness [26]. These games are almost uniformly slow-paced; for example, the "Slow Fun" Catching Dishes game for rehabilitation of spasticity in people with CP emphasizes slow stretching movements [10]. And in the "Virtual Wiihab" Mouse House game, players search for cheese in a house, moving by leaning on a Wii Balance Board [2].

However, as we found out during a year-long participatory study, children with CP are more interested in playing fast-paced action games similar to those played by their peers without CP. Action games are characterized by rapid movement and decision-making in a game world, and challenge the player's physical skills and coordination. Commercial examples include Activision's Call of Duty series, Ubisoft's Assassin's Creed, and Electronic Arts' NHL series. We particularly found that slow-paced games were a poor fit with the vigorous physical activity promoted by exergames.

It is no accident, however, that most exergames designed for people with motor disabilities are slow-paced. Design guidelines for such games - such as the BBC Accessible Games Standard [17] and the Game Accessibility Guidelines [7] - push toward slow-paced games. For example, guidelines encourage designers to *ensure that gameplay is not reliant on precise timing or movements* [8], and to *avoid multiple simultaneous actions* [11].

This paper reports on our experience designing six action games for children with CP at GMFCS level III. We argue that while traditional design guidelines are useful, when followed in a rote manner, they can lead to games that are sedate and boring. We take a different approach, where rather than focusing on what our target population cannot do, we instead push the limits of what they *can* do. This has allowed us to develop more nuanced design guidelines, and to create action games that our participants played and enjoyed over an eight-week home trial.

Children with CP at GMFCS level III have significant limitations in their abilities that make it difficult for them to play traditional action games. Limitations in their manual ability make it difficult for them to aim precisely and rapidly, or to manipulate numerous controls concurrently. 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 perform accurate gross-motor movements, reducing attention available for actual gameplay. 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. We have nevertheless found approaches helping to design successful action games for children with CP. These are drawn from iterative testing of numerous versions of our games, where we aimed to make the games action-oriented yet still playable. For example, we concluded that:

- Gameplay can be time-sensitive (such as found in the carefully timed running and jumping of a platformer game.) But the geometry of the game should permit pausing and retrying, the control scheme should be simple, and the penalty for errors should be low.
- Gameplay can involve high-speed navigation of a level (e.g., a racetrack.) But the level should be designed to have linear progression, should avoid obstacles, should not permit collisions between players, and should not require accurate aiming.

Following these approaches, and motivated by the proven effectiveness of bicycles in supporting vigorous exercise [25], we developed a cycling-based exergame for children with CP that contains several action-oriented minigames. Five children played the games over an eight-week home trial. All five children were capable of playing the games, found them enjoyable, and played enthusiastically over the full eight-week period.

This paper is organized as follows. We first describe action games and the challenges that children with CP face when playing them. We then review related work on action games and games for people with disabilities. Next we show how the iterative design of our minigames led to successful design recommendations. Finally, we draw broader lessons for designers of games for people with motor disabilities.

ACTION GAMES

Action games are exciting, fast-paced games that test the player's manual ability and hand-eye coordination [1]. Examples include car-racing games, first-person shooters, sports games, dancing games and platformer games. In most action games, players control an avatar performing a wide set of actions such as walking, jumping, aiming, shooting and throwing. Action games are tremendously popular: in a survey by Kutner and Olson [16], action games represented the top nine favorite games of middle-school boys, and seven of the top ten favorite games of middle-school girls.

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.

Action-oriented exergames and children with CP

The fast-paced mechanics of action games challenge players' attention, visual-motor integration and visual-spatial processing skills [24]. These challenges can be barriers to play for children with CP [10], particularly so in exergames, where the physical challenges of the games are extended to vigorous exercise.

Based on the definition and classification of CP [22], characterization of action-based games [24] 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. Children with CP have reduced manual ability [22]; those classified at the Manual Ability Classification System (MACS) level II (as with most of our participants) can handle most objects but with reduced quality and/or speed of achievement [6].

Standard game controllers have been used successfully in studies involving children with CP [5,13]; however, our participants found it hard to use common control schemes. Specifically, the children 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 manipulations are required in popular commercial action games.

Gross motor control

Children at the Gross Motor Function Classification System (GMFCS) level III CP have decreased motor control in both legs [21] 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 that manifest high levels of stiffness, often causing their legs to pull together, turn inward, and cross at the knees [18]. This makes it difficult to perform 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 [13]. We observed that children 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 skills actions is required to aim a tennis racquet at an approaching ball. Children with CP have lower performance in visual-motor integration tasks than children without CP. Even though eye responses in children with CP can be as fast as in children without CP, hand movements are slower and less efficient [23].

This ability is critical in action games for activities such as aiming, dodging, or jumping onto a moving platform [24].

Visual-spatial processing

Over 83% of children with CP present seriously affected visual-spatial processing abilities [15]. 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 to "lead" a moving target when shooting [24].

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 children with CP [9]. 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.

Our research question is therefore whether it is possible to design action-based exergames for children with CP that are playable despite these challenges, and that are fun to play over the long term. With this question in mind we identify principles for designing games that are playable, yet still action-oriented. To our knowledge, we are the first to address this question.

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 [3,7,8,11,17,19,27]. These guidelines are the product of experts in game design and accessibility standards.

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 paper 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. Throughout the paper, we refer to these as "traditional guidelines".

- *Avoid fast pace* [11]: game elements should move slowly to allow the player time to react. This conflicts with the fast-paced nature of all action games mentioned above.
- *Do not require precise timing* [7]: 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 relies on the player jumping between platforms and dodging enemies' attacks at the right time.
- *Provide a simple control scheme* [7,11,17,27]: reduce to a minimum the number of 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.
- *Do not require multiple simultaneous actions* [7,11,17]: 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.
- *Avoid repeated inputs (button mashing)* [7,17]: do not require rapid consecutive pressing of buttons. This guideline conflicts with the defining nature of action-fighting games, like Capcom's Street Fighter, where players punch, kick, block, jump and dodge attacks quickly and consecutively using different buttons.
- *Automate the player's input* [27]: reduce the need for detailed control by anticipating the player's intentions. Examples include steering assistance to avoid obstacles and automatic target lock-on.

All but the last guideline conflict with the nature and feel of action gameplay. When applied literally, these will 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 [4,10,20], spinal cord dysfunction [26], stroke [3] and multiple sclerosis [19].

For example, Geurts et al. present four minigames designed specifically for children with CP [10]. 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 [2]. 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 would not be appropriate. Additionally, following the guidelines makes the user group that can benefit from the games as large as possible. 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 in the context of our Liberi exergame.

THE LIBERI EXERGAME

The goal of Liberi is to allow children with CP (GMFCS level III) to participate in vigorous physical activity while socializing with friends. Liberi is played using a stationary recumbent bicycle, as shown in Figure 1. The bicycle 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. Our participants have proven capable of transferring from a walker or wheelchair to this unit and engaging in vigorous pedaling activity. Players use a standard Logitech wireless game controller. They aim with the left joystick and invoke game actions with the A button. Liberi was implemented using the Unity game engine.

The game's title, "Liberi", comes from the Latin word for "the free people". 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 2) that gives access

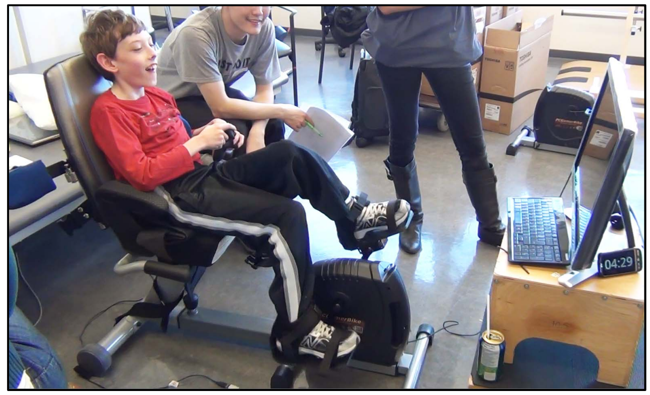

Figure 1: Child playing Liberi

to different regions containing minigames and to various shops where players can purchase rewards gained from long-term play of minigames, such as costumes, weapons and crafting materials.

There are six minigames in total, three of which are discussed in this paper. 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, 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.

Design Method

We followed a participatory, iterative design approach, with a team including ten youth with CP, a pediatrician specializing in children with CP, computer scientists, a physiotherapist, and a mechanical engineer. We also received offline advice from a professional game designer, an exercise psychologist, and a kinesiologist.

Three of our youth with CP 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 child was at MACS level IV, one was at level III, three were at level II and five at level I.

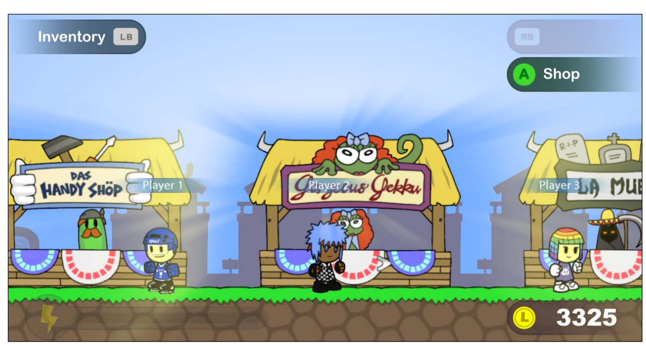

Figure 2: Players congregating in Liberi's central plaza

We held seven design and evaluation sessions with the team over a period of 12 months. From these we learned about the children's abilities, gaming experience, and preferences for game features. Through brainstorming sessions, the children provided ideas of games and drawings of characters. We adapted and included these in the final game. In each design session we tested several aspects of the game in terms of usability, playability and fun, and we gathered feedback by interviewing the children.

We discovered that our participants had an overwhelming preference for action games, strongly influencing their game design ideas. This motivated us to try to design action-oriented exergames playable by this user group.

After the evaluation sessions, we conducted an eight week home trial in which we gave the latest version of the game to five of these ten youth who played it at home. The game server was open daily for a 1.5 hour period. The participants were given an exercise prescription of 30 minutes of activity, five times per week. Participants were free to determine when (and whether) they wanted to play. On average, participants played 136 minutes per week, in line with the prescribed amount. They achieved an average cadence of 31 rpm in each session, consistent with moderately vigorous activity.

Three minigames were available initially, and an additional three were introduced on two week intervals. After the trial, we applied a custom Likert scale questionnaire to evaluate players' experience with each minigame, and conducted personal interviews with each child.

FINDINGS

From our experience designing and testing these action-based exergames, we found that it is possible to build action-oriented exergames that children 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 before being deployed in a home trial. Each game evolved significantly, progressing from poor playability to receiving significant play in the home setting, with high reported fun. These sections illustrate by example how it is possible to overcome the challenges of building action games for children with CP.

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 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 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:

- 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.

The first version of Dozo Quest included all of these problematic mechanics. In our first testing session with the game, the children could play for only a few tens of seconds until they could not advance further and gave up.

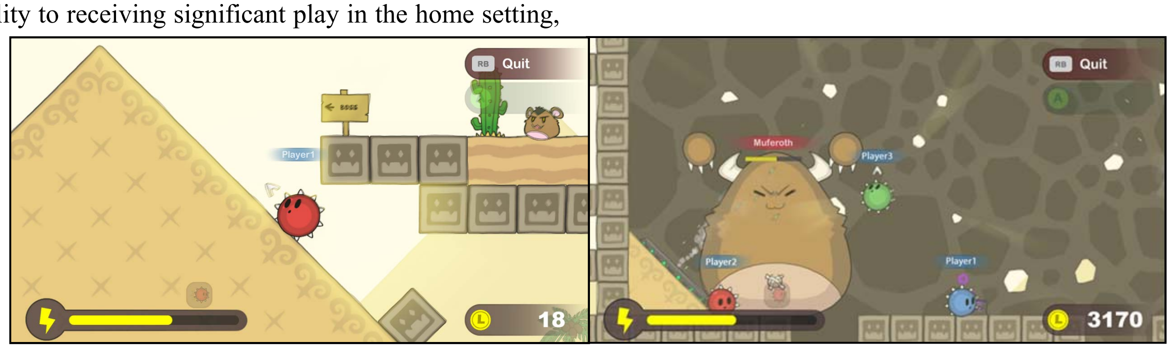

Figure 3: The Dozo Quest minigame. Left: players advance through the level. Right: players fight the final boss.

When we asked them whether they found this version of the game easy to play, only two children agreed (score of 4 or higher on a 5-point scale), one was neutral and three disagreed (score of 2 or lower). 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 get on the mobile ones”, “I would remove the rotating block you were supposed to get up on” and “It would be good to have a bit more of a linear progression through the whole level, [be]cause I can’t really decide whether to jump up over the platform or stay on the ground and when I do one I could not really figure out whether I needed to get back”.

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 children 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.

Experience and 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.

Following these changes, all of our 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.

Dozo Quest was available for six weeks of our trial. The children played it for an average of 37 minutes per week, equivalent to one of their recommended five play sessions. The children expressed that they found the game easy to play saying: "Timing my jumps was kind of easy" and another said "I had to time it [jumps and dashes] really well… I found that fairly easy". About the boss they said “I liked the boss fight… It was a lot of fun” and “I liked killing the boss”.

According to the post-study questionnaire, four children agreed that the game was challenging, easy to play, and physically tiring, while the fifth child was neutral. All agreed that the goal of the game was clear and simple and that they had fun playing it.

The Bobo Ranch minigame
In Bobo Ranch, players control birds that are in charge of quelling a sheep rebellion on a ranch (Figure 4). 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 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.

Figure 4: Left: Initial version of the Bobo Ranch minigame. Right: The revised version.

Why creating such a game is challenging

Some of the mechanics in this type of game are difficult to perform for children 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 child felt neutral about it. However, the players' difficulty in collaborating indicated that redesign was required.

What special measures make the game playable

By testing with the children 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.

Experience and results

We modified Bobo Ranch to take into account these two recommendations. The resulting game is shown in Figure 4 (right). 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 4 (right) 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.

Bobo Ranch was available for the last three weeks of our trial. The participants played the game for an average of 14 minutes per week, about 10% of their weekly playtime.

The children expressed their happiness with the final 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". They 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." The game was intended for collaborative play, and players clearly highlighted the game's difficulty when playing alone: "I tried to play it solo once and ended up losing almost all my money.", "Oh boy! This is not a game you play alone."

According to the post-study questionnaire, the five children 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 child did not find the goal of the game clear, simple or easy to play, and felt neutral about its fun.

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 5 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 children 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.

What special measures make the game playable

To make Gekku Race playable by children 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.

Figure 5: The Gekku Race minigame.

Experience and 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. This value was set for each participant before the home trial in consultation with a physiotherapist.

Gekku Race was available for all eight weeks of the trial. Each child played an average 80 minutes/week, or a total of 59% of time played. (This weekly percentage was initially high, and decreased as other minigames became available).

The post-trial questionnaire indicated that four players agreed that Gekku Race was challenging and physically tiring; the fifth child did not find the game challenging, and felt neutral about the game being physically tiring. All five players agreed that it was fun to play, the goal was clear and simple, and it was easy to play.

During the interview, several participants expressed their enjoyment of the game with phrases like: "Shooting cashews at the others is fun" and "I liked the most the chance to be competitive with everybody else". About the playability, one player said "I think is good that you are focused on pedaling forward and not worrying about turning and so wasting energy and I guess that's good".

LESSONS FOR DESIGNERS

Our core lesson is that it is possible to create action-oriented exergames that can be played and enjoyed by children 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 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.
- *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" [27] 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.

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.

Application to Other Populations

Our target population is significant in numbers: 67.2% of the roughly 800,000 people with CP in the U.S. are classified at GMFCS levels I, II or III [14]. 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.

Our one participant 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 children 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. [26].

CONCLUSION

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 children with CP at GMFCS level III.

Based on a year-long participatory design process including children with CP, we derived a set of design recommendations that preserve the core message of traditional guidelines, while mitigating their push to slow-paced gameplay. These recommendations allow the development of high-action exergames playable by populations with significant motor disabilities. A group of five children with CP found our games easy to play, fun and engaging over an eight-week home trial.

Our next steps will involve larger home trials designed to help us evaluate the efficacy of these games in improving health and social engagement.

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