# Accessible Play in Everyday Spaces: Mixed Reality Gaming for Adult Powered Chair Users

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The advent of affordable and powerful mobile technology has allowed for explorations in mixed reality that merge virtual and physical space. However, the social and entertainment value and efficacy of mixed reality platforms for adult powered chair users has not been widely explored. In this paper, we introduce the *Mobility Games* project, which aims to produce a series of inclusive entertainment technologies and services for people who use powered chairs. We describe our first offering: an accessible, social mixed reality game for co-located mobile play in everyday spaces. Findings from two exploratory field studies and a post hoc observer survey show that adult powered chair users found the game to be entertaining and used a variety of path strategies as they learned to play the game. An initial set of theoretically- and empirically-informed guidelines for making mobile mixed reality games accessible to adult powered chair users with diverse abilities is proposed.

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## 1. INTRODUCTION

In the last decade, the prevalence of modern mobile technologies—phones, tablets, readers—supported by vast, dense networks have brought technological mediation to everyday spaces. Smart devices featuring rich displays, wireless connectivity, and access to a wide array of services and applications make up the mobile landscape. Against this backdrop, new ways of interacting with people, places, and things through computers has emerged. In the same way that virtual reality inspired a

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vision of shared real and virtual space in the nineties [Milgram and Kishino 1994], the widespread use of modern mobile technology has shifted the focus back to mixed reality—a blend of physical and virtual space mediated by these new technologies.

Projects such as Google's *Ingress* have demonstrated how mixed reality games can operate in everyday spaces using technology most people have on-hand, namely smartphones and tablets. In the wake of this and other efforts, gaming has surfaced as a significant area of interest in studies on mixed reality [Bonsignore et al. 2012]. Mixed reality game spaces are primed for multiuser, team- or group-based, competitive and cooperative play; they encourage a return to the physical and social roots of traditional games, such as tag and hide-and-seek, while retaining the benefits of virtuality [Cheok, Yang, et al. 2002; Nilsen et al. 2004]. In this way, mixed reality games are potentially well-suited for non-entertainment ends; indeed, the success of games for purposes beyond entertainment has been widely demonstrated [Michael and Chen 2005; Susi et al. 2007]. For instance, gaming has been shown to assist in reducing isolation and improving health and self-esteem for seniors [Mellor et al. 2008; Khoo et al. 2006]. The success of the game medium in these areas merits continued explorations of its effects on a range of individuals and settings.

However, studies in mixed reality, like many areas of research in HCI, have suffered from a narrow focus on the "ideal" average user, thus excluding the rich diversity of real human populations. The result is knowledge that may not be—and all too often is not—appropriate for a substantial segment of the population. Further, the artefacts that are produced—whether they be physical technology or a conceptual game—often require post hoc modifications and/or accommodations to be made accessible, which is an exclusionary and expensive practice. In short, these are problems of inclusion and access that, in research practice, require the involvement and respectful study of diverse end-users to avoid. While some research has sought to mitigate these problems, including studies featuring people with disabilities [Tzovaras et al. 2009; Brederode et al. 2005], people with chronic or rehabilitative illness or pain [Correa et al. 2007; Alamri et al. 2010], and the elderly [Khoo et al. 2006; Gamberini et al. 2009], little attention has been paid to providing entertainment and/or social opportunities for differently-abled users, such as people with mobility restrictions.

In this paper, we present empirical findings from two field studies and one post hoc observer study in which we assessed a social, mobile mixed reality game we designed to be accessible to adult powered chair users. Framed by universal design and entertainment theories, our research addresses mixed reality gaming for a diversity of users' needs, including alternative input and output devices, accessible information presentation, and inclusive play with non-powered chair users, such as friends and family. We developed the following exploratory research questions: (Q1) How effective is the mobile mixed reality game at providing an inclusive, social and fun experience for adult powered chair users? (Q2) How do adult powered chair users play the game in an everyday setting and in particular what strategies do they employ? The main contributions of this work are summarized below.

— To the best of our knowledge, this work is the first effort to address the social entertainment needs of adult powered chair users in a mobile mixed reality game setting.

— Our primary contribution is a set of empirical findings on the nature and entertainment value of a social, mobile mixed reality game from two field studies featuring members of the target group interacting with the technology and each other in a everyday settings.

— Our secondary contribution is an initial set of guidelines for includifying, or making inclusive, traditional games designed for people without disabilities through the use of technological augmentations, particularly mixed reality.

— Theoretically, we contribute an empirically-verified design grounded in inclusive design principles and built out of a user-centred design process.

## 2. BACKGROUND

Mixed reality is characterized as a fluid realtime combination of virtual and physical interactive environments [Milgram and Kishino 1994]. The degree to which the virtual and real intersect—defined as mixed reality—has been represented as a reality–virtuality continuum comprised of "augmented reality"—primarily physical space with some virtual augmentations—and "augmented virtuality"—primarily virtual reality with some physical augmentations [Milgram and Kishino 1994]. Since its inception, mixed reality has been explored along a number of interdisciplinary trajectories inspired by its home base of virtual reality. These include technologies to facilitate mixed reality experiences, especially body augmentations such as the head-mounted display (HMD); applications in traditional domains, such as medicine, training, and simulation; a focus on visual presentation, rather than the augmentation of other senses; and refinement of realtime rendering techniques, especially registration, or the placement of objects in relation to each other, the environment, and the user(s) [Azuma 1997; van Krevelen and Poelman 2009; Costanza et al. 2009; Thomas 2012]. As the field matured, new areas of application gained prominence, notably in the entertainment sphere with mixed reality games.

### 2.1 Mixed Reality Gaming

Mixed reality games—games played in mixed reality settings—run the gamut in terms of genre, sociability, physical activity involved, attributes of the physical space (such as size, type, materiality), technical sophistication, gear required, nature of the research conducted, and where on the reality–virtuality continuum they fall. Many mixed reality games are ports or reimagined translations of existing games. *AR²Hockey* [Ohshima et al. 1998], for example, featured a two-player air hockey setup—with table and paddles—and virtual pucks. A mixed reality version of a Rubrik's cube used a haptic interface for fine motor control with the fingers created by researchers in Japan and Thailand [Sato et al. 2003]. By the early 2000s, the gaming environment had expanded from tables and small rooms to wider areas and outside playing fields. For example, *Game-City* [Cheok, Wan, et al. 2002] implemented a city-wide multiplayer mixed reality game featuring tangible objects—treasure boxes—containing virtual treasures. A wearable computer featuring a HMD and fiducial marker tracking was provided to a single participant, who was able to view and interact with virtual objects in physical reality. *Human Pacman* [Cheok et al. 2004] sought to build upon these previous efforts by providing multiplayer gameplay in a large outdoor area using HMDs and networked wearable technologies.

The body of work on mixed reality unearthed a variety of challenges related to game design in mixed/virtual spaces large and small and the technologies used to facilitate mixed reality gameplay. Wired technology posed a problem for games requiring physical activity of any kind, even relatively minor actions, such as moving around a table [Nilsen et al. 2004]. Some specialized wearable technologies, such as HMDs, are not adjustable, thus excluding a range of users, including children [Nilsen et al. 2004] and many differently-abled and sized individuals—a population largely excluded from this work. Similarly, much of the technology, especially HMDs and

vest-worn laptops, are expensive, heavy and awkward. Software-wise, a lack of robustness in the technology—for instance, unreliable marker tracking, a restricted visual field, and the display of graphical elements in different fields of view (FOV)—can be disruptive and difficult to fix [Nilsen et al. 2004; Thomas et al. 2003; Ohshima et al. 1998]. Similarly, weather conditions pose a problem for viewing displays, whether they be mobile displays or HMDs [Thomas et al. 2000]. An alternative for mixed reality gaming that obviates many of these issues is a technology we used in our work: personal handheld mobile technologies, especially tablets and smartphones.

*2.1.1. Mobile Technology.* When cell phones, PDAs, and later smartphones and tablets arrived and blossomed within the consumer landscape, the technological face of mixed reality began to deviate from its roots in virtual reality. Notably, the clunky, heavy, head-worn displays—often inaccessible to bodies that deviate from the norm—were replaced by a variety of primarily handheld mobile devices [Höllerer and Feiner 2004]. Although mobile displays are typically more limited than HMDs and similar technologies, potentially affecting immersion [Cheok et al. 2004], a handheld, mobile approach makes possible more spontaneous forms of play that do not require special technologies and are therefore more accessible. For instance, *Pirates!*, a context-aware, networked, multiplayer mixed reality game, was played over handheld computers affixed with proximity sensors [Björk et al. 2001]. An elaborate version of chase, *Can You See Me Now?* [Crabtree et al. 2004; Benford et al. 2006] had teams of virtual players—operating over the Internet—chasing four runners around an entire city. A mobile mixed reality version of capture the flag [Cheok et al. 2006] explored realtime virtual and co-located roleplaying. The location-aware game *Viking Ghost Hunt* [Paterson et al. 2010] used mobile phones and multimodal input to allow players to interact with virtual points presented as paranormal phenomena related to old Viking sites in Dublin, Ireland. Our work seeks to build upon these previous efforts by exploring a mobile-based mixed reality game for an overlooked audience using the latest smartphone technology. Additionally, our focus is on providing entertainment that facilitates social interaction, a notion that has already received some notice in the area of mixed reality gaming.

*2.1.2. Mixed Reality Gaming for Social Interaction.* The increased opportunity for social interaction and multiplayer gameplay provided by co-location in physical space was not lost on early researchers of mixed reality games. Drawing from the tenets of ubiquitous computing, researchers involved in the *Pirates!* project [Björk et al. 2001] aimed to create a social, context-aware mixed reality game rooted in traditional gameplay, particularly duel combat. A collaborative multiplayer co-location setup built upon social computing principles, including mediated human-to-human contact, was facilitated by *Touch-Space* [Cheok, Yang, et al. 2002]. In *Human Pacman* [Cheok et al. 2004], competitive elements—Ghosts seeking out Pacmen—were complemented by collaborative elements in the form of Helpers who provided advice and encouragement from outside of the playing field. Our game draws on the rich design and research history established by these earlier efforts—notably the success of the approach for social interaction, multiuser play, and the inclusion of collaborative elements into competitive play.

Research on the social lives of adults who use powered chairs has shown low levels of social interaction generally [Dicianno et al. 2009; Evans et al. 2007; Liptak 2008]. This suggests that having access to powered mobility is not enough. An opportunity for social interaction in a barrier-free environment may be appropriate, but this needs to be explored. In this work, we seek to do so through a mixed reality

gaming as an effective and enjoyable form of social entertainment for this overlooked audience in need of accessible opportunities for social interaction.

### 2.2 Accessible Entertainment and Mixed Reality Gaming

Accessible entertainment is the notion that pleasurable activities and experiences should be accessible to all people regardless of ability. The move towards accessible entertainment represents a shift occurring in contemporary approaches to design, namely inclusive [Clarkson 2003], ability-based [Wobbrock et al. 2011], and universal design [Preiser and Smith 2010]. A range of human ability and experience is now being recognized as a necessary starting point to design, while the traditional approach of narrowing the design lens on a particular subset of the population, often in an unnecessarily specialized and *ex post facto* fashion, is falling out of favour [Clarkson 2003; Preiser and Smith 2010]. Instead of the individual being viewed as disabled, society and its cultural appendages—technologies, services, activities, environments—are seen as disabling forces that exclude a large portion of the population [Hughes and Paterson 1997; Clarkson 2003]. An important role of the contemporary designer, regardless of specialty, is to recognize, learn about, and design for the rich diversity of users that make up humankind. As such, the driving motivation of our work is that everyone deserves equitable access to entertainment. However, the lack of research in this area provides little in the way of guidelines for the design of inclusive entertainment, particularly in a mixed reality game for people with mobility impairments. Our primary goal is to contribute to the expansion of this research area with empirical research on accessible entertainment.

Accessible computer entertainment is especially deserving of attention for several reasons. Computer technology, when designed inclusively, provides positive social opportunities and personal autonomy for people with disabilities [Abascal and Nicolle 2005]. Further, social exclusion caused by the digital divide is a real threat to the inclusion of people for whom these technologies are not designed [Fitch 2002]. The greatest hurdle in facilitating access to computer technologies, and subsequently computer entertainment, is twofold: widespread misconceptions of the interests and abilities of people with disabilities to engage with computer technologies combined with the choice of designers and stakeholders to design in ways that are not inclusive or universal [Abascal and Nicolle 2005]. Consequently, certain users are excluded not only from technology use, but from the benefits directly related to technology use, including social interaction and pleasure through computer entertainment.

In the area of computer entertainment, computer games are rapidly increasing in popularity, particularly with non-conventional target audiences such as older adults and people with disabilities. However, these games rarely address audiences who have different abilities, limitations, needs, or motivations for play compared with younger users or users without disabilities [Grammenos et al. 2009]. In order to create more inclusive opportunities for gameplay, games should aspire to be fun as well as account for differences in needs, abilities, and interests, including using larger fonts, alternative input and output modalities, slower pacing, and having fewer distractors [Duh et al. 2010; Allaire et al. 2013]. Game developers should also consider players' need for motivation [Boyle et al. 2012] and fun [Ijsselsteijn et al. 2007; Korhonen et al. 2009; Deterding et al. 2013]. Approaches to game design that are accessible and inclusive, such as universally accessible game design and includification, are appearing in response to increased awareness of these issues [Grammenos et al. 2009; Barlet and Spohn 2012; Yuan et al. 2011].

Research on accessible computer-based gaming for adult powered chair users remains underexplored. However, a developing area of research has looked at mixed reality and mobile gaming for children who use powered chairs, from which we draw inspiration. *pOwerball* [Brederode et al. 2005], an augmented tabletop game, was designed to create a playful social experience for children of varying ability and health but there was no further exploration of its applicability to adult users. A mixed reality game for training children with severe mobility impairments to use wheelchairs has been developed; the space used floor projectors and wheelchair movement as display and input, respectively [Secoli et al. 2011]. The limitations of these projects, aside from being designed for children, is that they are location-restricted (the tabletop and floor projections) and require sophisticated technology.

Although no research in mixed reality gaming has, to the best of our knowledge, focused on adult powered mobility users, several initial efforts to provide such entertainment and to study its effects exist. However, many have been motivated by non-entertainment objectives. GAME$^{Wheels}$ [Fitzgerald et al. 2006; O'Connor et al. 2000] was developed to help wheelchair users learn how to drive their devices; the tool is clinical in nature and restricted to wheelchair users. Similarly, *Virtual Reality Wheelchair Soccer* [Rossol et al. 2011] was created to pilot the researchers' adaptive virtual reality framework for wheelchair rehabilitation. In the entertainment sphere, KINECT$^{wheels}$ [Gerling, Kalyn, et al. 2013; Gerling, Mandryk, et al. 2013] was created as a toolkit for developers to enable interaction between games and powered chairs users through upper-body movement and gestures. The use of a mixed reality platform based on inclusive mobile technology has the potential to extend these efforts in gaming entertainment for play and training purposes to account for a more diverse selection of mobility devices, particularly mobility scooters.

## 3. THE MOBILITY GAMES PROJECT

The overarching goal of our work is to provide new forms of accessible entertainment and socialization opportunities for populations that may struggle with social isolation and inaccessible entertainment options, such as seniors and people with mobility disabilities. In this phase of the project, we sought to explore how mixed reality games designed for people who drive powered chairs, such as electric wheelchairs and mobility scooters, could be used to meet this goal. We were particularly interested in how mixed reality could be incorporated into everyday spaces, such as parking lots and parks, and be accessible and appropriate for powered chair use. As such, we developed a social, mobile mixed reality capture-the-flag game for adults who use powered chairs.

### 3.1 Capture the Flag

The capture-the-flag (CTF) game we developed, called *Powered to Play (PTP)*, draws upon previous efforts in mixed reality gameplay with smartphones and the CTF-style genre, e.g. Cheok et al. [2006]. The game used geo-location and virtual gaming elements through smartphones and publicly available digital services. Here, we will describe the game using the mobile systems taxonomy developed by [Dix et al. 2000]. See Edey et al. [2014] for complete details.

3.1.1. Gameplay. CTF-style games involve two teams competing for each other's flag. The main task of the game is for the player to capture the flag from the opposing team's territory and return it to their home territory. Other tasks include defending the home territory and preventing members from the opposing team from taking a

captured flag back to their home territory. This is done by whittling away the health points of opposing team members through proximity (importantly, *not* touch).

3.1.2. Interface. The game takes place in physical space that is augmented by virtual elements visible through the smartphone app. A full list of these elements is available in Figure 1. The primary elements are: (1) the player and flag icons; (2) the game boundary and team territories; (3) the player's health and shield energy bar; (4) the team and player points; (5) the timer; and (6) the map controls. Each player icon is encased by a gray circle that acts as an indicator of GPS accuracy. A captured flag is represented in the player icon with a smaller version of the flag. The energy and health meters slowly (in that order) decrease when the player is in proximity to a player from the opposing team and increase when the player is in their team's health circle. The background is a simple representation of the physical environment generated in realtime by the Google Maps API.

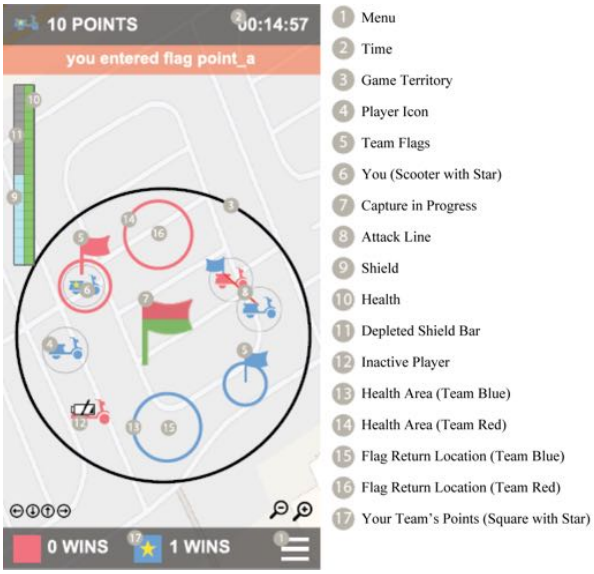


Fig. 1. Main game screen with legend of game elements. Map data ©2013 Google.

3.1.3. Platform. The game was developed for Android and iOS-based smartphones using an open-source, cross-platform, JavaScript framework called *Appcelerator Titanium*. A dedicated server was setup for the game. Each instance of the game app running on individual smartphones is aware of any other apps running at the same time via the server. The physical spaces were chosen ahead of time; the use of powered chairs (which require a flat surface away from tall landmarks and structures) and the nature of the gameplay (which requires a large space) determined what locations were suitable. Smartphone location was determined through the Global Positioning System (GPS); the use of a proximity circle enclosing each player icon was used to mitigate position inaccuracies.

3.1.4. Inclusive Design Approach. The game was designed in an inclusive fashion based on guidelines developed from Idea Jams with powered chair users (see Section 4). For instance, where other mixed reality games of this type (e.g. Cheok et al. [2006]) used physical flags that may be difficult for someone in a powered chair to pick up off of the ground, *Powered for Play* uses virtual flags, rendering this mechanic accessible. See Dolinar [2014] for more details about the inclusive design process.

## 4. PRELIMINARY IDEA JAM STUDIES

As a first step in our design process, we enlisted 27 powered chair users for four Idea Jam sessions at locations across the greater Toronto area: Ryerson University, the University of Toronto, the Toronto District School Board, and Variety Village in Scarborough. Idea Jams are a type of focus group in which stakeholders develop a specific concept by actively contributing their ideas and solutions in a hands-on, workshop setting [Moser et al. 2014]. In our case, we asked participants to help develop a game that could be mediated by smartphones or other mobile devices in a mobile setting. Before the session, participants were given a short presentation on what games are, what game elements exist, and what game mechanics can do. They were tasked with coming up with at least one game concept that involved mobility and included the use of powered chairs. They were then placed into small groups and provided with paper, pens, and other tangible materials (such as Lego, fabric, tubing, etc.). They were given one hour for the brainstorming stage, and then shared their ideas with the rest of the group and the researchers in a group discussion. Data analysis involved a thematic analysis of the qualitative discussion data and statistical analysis of the questionnaire data, which included items on the Idea Jam experience, interest in the game ideas generated, and motivation for participation.

A number of factors that should be considered in the design of mixed reality games for powered chair users were identified; see Dolinar [2014] for details. Age correlated with how often participants play video and physical games, with younger people playing games more often than older people. The level of enjoyment participants experienced was affected by how much they enjoyed the games under discussion; this in turn affected their level of interest in participating in the game design activity. Preference for simple, popular games with a social element was expressed. Intergenerational gaming that was inclusive of different levels of ability and expertise was also a common thread.

As a complement to these findings, eight key recommendations based on the identified themes and supported by the statistical findings were generated and then implemented in *PTP*; see p. 108 of Dolinar [2014] for a full comparison The recommendations are:

(1) An inclusive game where multiple people with various skills and abilities can play. *PTP* is a team game requiring multiple participants. In addition, players on foot also played the game.
(2) Intergenerational gaming. In our studies, powered chair users of different ages played together. Children playing in the parkette (Study 2), on skateboards and on foot, asked to play the game, but we were unable to include them due to (a) a lack of ethics approval to include people under 18 and (b) the logistics of obtaining parental approval in an ad hoc context.
(3) To socialize with others. Being a team game, players must play with others. As such, the game provides opportunities to meet and collaborate with new people towards a common goal.
(4) A fair playing field, i.e., one that balances the skills and abilities of all players. *PTP* offers different roles of varying skill level to players. Players can choose to take on defensive or offensive roles, depending on preferences and skill level. Players can either proactively offer to take on certain roles or they can evolve as the game is played.
(5) To be challenged. The flag is placed in a random and unknown position at the beginning of the game, thus offering an initial challenge. The tension between offensive and defensive movements changes depending on teammates and

opposing players. Tracking and adapting to the different strategies of the other teams' players offers on-going challenges. The concept of levelling up was not implemented in the current version of *PTP*; however, it is possible (e.g. by reducing the home base diameter, moving the flag position during the game, etc.)

(6) Accessible and easy to use equipment and interface design. The virtual interface and touchscreen was made more accessible using the *Tecla Shield* single switch control.

(7) An outdoor play space. *PTP* was designed to be played outside using a GPS system. All studies reported in this paper were played outside. An indoor game is possible but requires a different positioning technology.

(8) Have opportunities to improve their skills and abilities through increasingly challenging game tasks.

These findings set the foundation for our work: an inclusive game based on a popular outdoor game genre, capture-the-flag, which features the physical and social aspects in which participants expressed interest.

## 5. FIELD AND POST HOC OBSERVER STUDIES

Two field studies at two community sites were undertaken to investigate the efficacy of the capture-the-flag game as a social entertainment platform for adult powered chair users in everyday spaces. Given that no research has investigated the value of mobile mixed reality gaming for adult powered chair users and its effects, we adopted an exploratory approach with high-level research questions addressing the usability and engagement factors involved in playing such a game with powered chairs.

A post hoc survey-based study with members of the research team was conducted to augment findings from the field studies with feedback on and perceptions about the game from the perspective of participants without disabilities. In addition to enriching the field study data, the goal was to assess the game's inclusivity for non-powered chair users and develop an initial impression of how a game for powered chair users and friends, family members, and community acquaintances who do not use powered chairs would be received.

Our overarching goal across these studies was to capture a rich sense of the nature of adult powered chair users' experiences with such a platform, generate an initial set of findings and guidelines, and develop empirically-grounded trajectories for further research in this area.

### 5.1 Participants

Thirteen powered chair users (8 evenly split by gender in the first study, and 1 man and 4 women in the second study) ranging in age from 18 to 24 years (6 participants), 25 to 34 years (1 participant), 45 to 54 years (3 participants), 55 to 64 (3 participants) participated in the field studies. Participants with more than one year of experience with their powered chairs were recruited within the greater Toronto area by email, fliers and posters issued by or displayed at collaborating institutions, organizations, and stores, word of mouth, and cold calling. The majority of participants (92%, or 12 of 13) had completed at least high school level education, with 39% (5 of 13) having completed college, 15% (2 of 13) university, and 15% (2 of 13) graduate studies. All participants in the first study used power wheelchairs, while in the second study 1 participant used a three-wheel mobility scooter, 2 used a four-wheel mobility scooter, and 1 used a power wheelchair, with 1 participant switching between either a power

wheelchair or four-wheel mobility scooter depending on the weather. All participants were dependent on their powered chairs to get around.

Five observers (3 women and 2 men) who were part of the research team and present at at least one of the field studies took part in the post hoc observer study.

### 5.2 Context

The first field site was a parking lot (about 200m x 200m in area) at the Scarborough Centennial College campus; the second study took place at Joel Weeks Parkette (0.95-hectare park space with a playground, walking paths, a skateboard area and a basketball court) in eastern Toronto, Ontario.

The post hoc study was conducted online using email to solicit participation from members of the research team and *LimeSurvey*, a web-based survey application, to deliver the survey and record responses.

### 5.3 Measures and Instruments

5.3.1. Questionnaires. Basic demographic information, such as age, gender, level of education, and type of powered chair, was collected in a pre-play questionnaire. The questionnaire also included multiple choice and open answer questions on what participants liked and disliked about their powered chair, computer and cell phone usage, types of video (e.g. Nintendo) and physical (e.g. soccer) games played and how often, game equipment used, general and game-related touchscreen technology usage (if applicable), actions required to interact with touchscreen technology, and difficulties experienced with the technology. Also included were questions on how and with whom participants learned to use their powered chair, preferred learning methods, and problems experienced with general usage.

The post-play questionnaire contained thirty-three questions directly related to the game experience. Participants were asked about their overall enjoyment level (five-point Likert scale), activity level in the game, and aspects of the game they liked and disliked (open answer). Seventeen relevant items answered using a three-point scale (1 being "no," 2 being "sort of," and 3 being "yes") were included from the Game Engagement Questionnaire (GEQ) [Brockmyer et al. 2009]. Example items include: "I lost track of time," "The game felt real," and "I lost track of where I was." Two additional questions were added: "I was bored" and "I would rather be doing something else." Further five-point Likert scale questions addressed ease of use in learning how to use and actually using the touchscreen, finding players and objects in the game, zooming, picking up the flag, working as a team, and avoiding obstacles. Open-ended questions asked what aspects of the touchscreen were easy or difficult and what improvements participants would suggest for the game. At the end of the post-play questionnaire was the NASA Task Load Index (NASA-TLX), an instrument used to measure perceived workload in relation to a task [NASA n.d.; Hart and Staveland 1988; Hart 2006], in this case strategy-based gameplay.

The post hoc study used a web-based survey with six open-ended items focusing on the observations, experiences, and insights of the researchers who acted as observers during the field studies. Items were developed by the first author, who was not a respondent; see Section 5.5.5 for the full set of items and responses.

5.3.2. Game Metrics. The game itself was used to track and collect data on instances of the game, individual players, and objects within the game. Using the Google Maps API, the game recorded longitude and latitude coordinates and timestamps for player path data over the course of the game. Events, such as when flags were picked up

and dropped or when players lost all of their energy, were logged. The length of the game, the points collected per team, and basic game configuration data were also recorded. Data was logged each time an event was executed.

5.3.3. Data Analysis. Path data was collected as an indicator of route preference. In the transportation and urban planning fields, path data is used to better understand driver and pedestrian decisions regarding route choices and route planning. Prato *et al.* [2011] found that route choice behaviour is a function of reducing travel time and distance, finding the shortest distance, avoiding congestion, habit, familiarity with the route, and cognitive attributes, such as spatial and time-saving abilities. Gräßle and Kretz [2011] found that while pedestrians are often influenced by the quickest or shortest route, they are also influenced by other factors, such as scenery or surface type. Within the location-based game community, path choice analysis does not seem to be a prominent assessment tool for game strategy. However, we suggest that, based on the work of transportation and urban planning researchers, route choices may provide some evidence of player preferences and strategy. For example, a player may play as quickly as possible to win, taking the shortest route as part of that strategy; or they may take a more familiar route, which may not necessarily be faster, but be more comfortable and afford better accuracy (such as not getting lost). Powered chair users are a special case because they are considered pedestrians by the government (e.g. as per the Ontario Ministry of Transportation definition of personal mobility devices [2015]), even though they are also operators of a motorized vehicle, the use of which involves driving tasks, such as steering, braking, accelerating, and monitoring displays. Further, compared to other pedestrians, powered chair users can travel faster than those walking or running, but they may also be more often impeded by environmental barriers, such as curbs. As such, route choice behavior may be affected by factors related to pedestrians, drivers, or both.

### 5.4 Procedure

Prior to the start of each session, the grounds were prepared for the game and presence of participants. This included sanctioning off potentially hazardous areas with orange safety pylons and tape (as required by ethics to mitigate the risk of harm) and removing unsafe objects in the area, such as rocks and garbage. An access meeting point was scheduled in advance with the TTC Wheel-Trans service to facilitate the arrival of participants.

At the start of each session, participants were greeted and matched with a partner on the research team or volunteer from the lab who would direct and support them for the duration of the session. The research partner provided information on the study, ethics, and helped read and fill out the questionnaires when necessary. They also explained the rules of the game and supported the participant during gameplay, particularly to direct them away from potential harm due to close interactions with other powered chair users, other people in the vicinity, and environmental hazards that could not be removed for the study. Each participant was equipped with a flip camera to record audio, a mobile technology holder for mobility devices, Komodo OpenLab's *Tecla Shield* (gettecla.com) for one single-switch user, and an Android smartphone loaded with the game.

The session proceeded in two parts, i.e. two instances of the game were played per session. Participants were randomly grouped into teams of equal numbers, determined by the game application. They were then directed to play the game until one team earned ten points. Partners were directed to follow (whether by walking,

jogging or running when necessary) and provide additional game or technology support to the participant with whom they were matched.

After the games were played, participants filled out the post-play questionnaire, received compensation, and enjoyed a pizza dinner before ending the session.

In the post hoc study, members of the research team who took on an observer role during the field studies were solicited by email to fill out the web-based survey. Responses were collected in November 2014.

### 5.5 Results

In this section we present results from the questionnaires and data collected by the game application, particularly path data related to strategy and engagement, as well as responses from the post hoc observer survey. Some participants did not fill out every question on the questionnaires, in many cases because the question did not apply to their situation; this is reflected in to the ratio of answers beside each item.

5.5.1. Pre-Play Questionnaire. In answer to what they liked most about using their powered chair, participants reported enabled mobility (5 of 13), increased independence and freedom (4 of 13), and greater distances travelled (2 of 13). What participants liked least was encountering inaccessible spaces (6 of 13), the device breaking down (4 of 13), and the effect of weather (3 of 13).

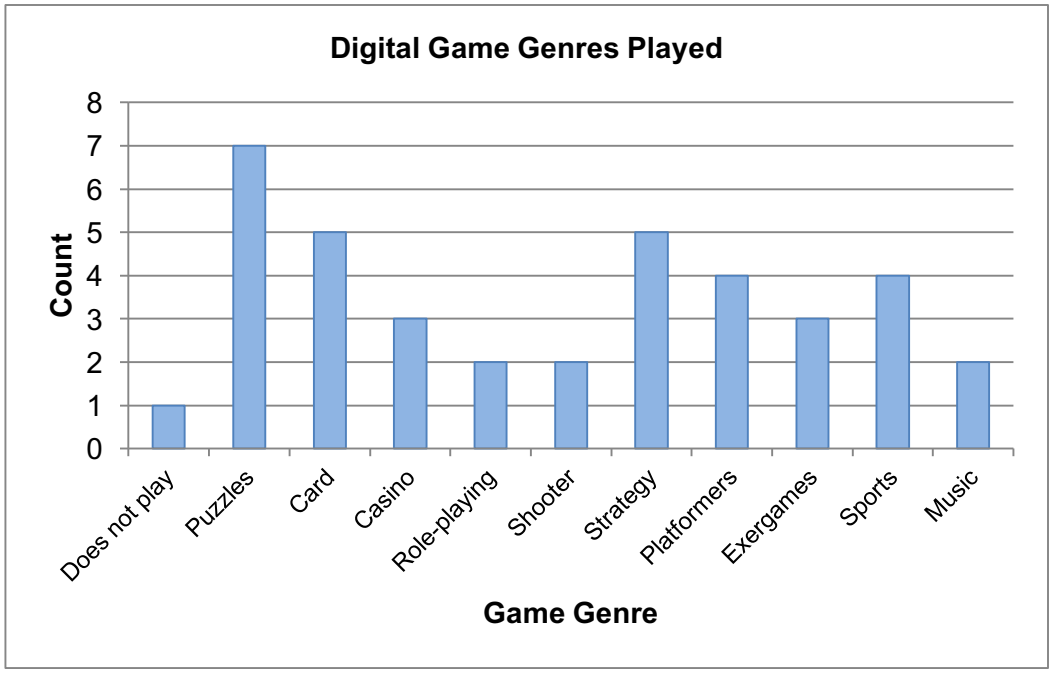


Fig. 2. Frequency of digital game genres played by participants.

The vast majority of participants reported using a computer everyday (11 of 13), with one reporting use once a month and another reporting never using a computer. The majority of participants used a smartphone (9 of 13) while the rest used a plain cell phone with no Internet features. Of those with a touchscreen-based phone, participants used an Android touchscreen phone (8 of 10), with two using Blackberries (1 of 10) or iPhones (1 of 10). While many did not report having difficulties using the touchscreen (4 of 10), others experienced difficulty using the on-

screen keyboard (3 of 10), with a few experiencing difficulty with a range of other issues related to using phone features, texting, and knowing functions.

Frequencies for digital game genres played can be found in Figure 2. Most participants played games on an Internet-connected computer (7 of 14), while others used their mobile device (5 of 13), or a console (3 of 13). The majority of participants played games for entertainment (11 of 13), while many played as a distraction (7 of 13) or to pass the time (7 of 13), and some to be with friends (5 of 13); escaping from reality (3 of 13) and personal interest (1 of 13) were not popular reasons.

Of the participants with touchscreens, all used them to play puzzle games (9 of 9) and many used them to play casual games such as *Angry Birds* (5 of 9). To play these games, participants need to touch or press controls (7 of 9), swipe (7 of 9), touch the screen in different places (7 of 9), type (4 of 9), or given voice commands (1 of 9).

When asked how often they play games using their powered chair, most participants reported never (6 of 13), with the rest divided between once a month (3 of 13) and everyday (3 of 13), and one user reporting that when they play games it is always with their powered chair. The types of games participants played on their powered chairs included computer games, movement games such as tag and hide and seek, although five participants chose not to respond to this question.

Most participants learned how to use their powered chair on their own (9 of 11), with some being trained at the vendor (2 of 9) and others trained by occupational therapists or physiotherapists (2 of 9). Regarding *how* they learned to drive their powered chair, most users "just drove it" (7 of 13), many practice in a quiet traffic area until they were confident (5 of 13), and others felt it was similar to driving a car (3 of 13). Participants' preferred methods for learning how to drive powered chairs were: practice (7 of 13), a demo (6 of 13), a formal class (4 of 13), a social game (4 of 13), the Internet (3 of 13), and a single-player game (1 of 13).

Participants experienced a range of issues related to driving their powered chair. Many had trouble finding accessible washrooms (5 of 12), using public transportation (5 of 12), and using cell phones while driving (5 of 12). Some had trouble remembering to keep the battery charged (4 of 12), while others had trouble making sure drivers saw them on the road (3 of 12), judging space and distance perception (2 of 12), and terrain traversal, such as crossing streets, entering buildings and avoiding obstacles (2 of 12).

5.5.2. Post-Play Questionnaire. One participant did not fill in a post-play questionnaire. Scores for enjoyment, activity level, boredom, disinterest, and GEQ constructs are presented in Table I. The median enjoyment level was 5 and the median level of activity was 4.5. The GEQ medians per construct were as follows: 1 for absorption; 1.5 for flow; 2 for presence; and 3 for immersion.

Table I. Descriptive statistics for enjoyment, activity level, and GEQ constructs.

| Questionnaire Item | Median | Mode | Range | Interquart. |
|---|---|---|---|---|
| Enjoyment | 5 | 5 | 1 | 0 |
| Activity Level | 4.5 | 5 | 2 | -1 |
| Boredom | 1 | 1 | 1 | 0 |
| Disinterest | 1 | 1 | 1 | 0 |
| GEQ: Absorption | 1 | 1 | | |
| GEQ: Flow | 1.5 | 1 | | |
| GEQ: Presence | 2 | n/a | | |
| GEQ: Immersion | 3 | 3 | | |

Participants provided a range of responses when asked what they liked and disliked about the game:

*Positive Comments.* Four participants enjoyed playing a team-based game, e.g. "[I liked] being on a team" (Participant #7) and "I liked … protecting my teammates" (Participant #3). Four also enjoyed playing a game that involved moving around rather than being stationary, e.g. "Moving around – very freeing" (Participant #7). Two mentioned that they appreciated being able to use their wheelchair in the game, e.g. "The fact that wheelchairs were used to capture the flag" (Participants #1). Getting the flag was mentioned by three participants, and two enjoyed using the smartphone technology in a new way, e.g. "Technology and tracking and use of smartphone" (Participant #6). Other comments included the ability to attack other players by proximity, being outdoors, employing strategies, and having fun, e.g. "I like stealing the flag from other people" (Participant #8). One participant's grandson participated in the game; having him participate was rewarding to this participant, who commented on the exercise and social interaction the game afforded her grandson. According to Observer #5, the mother of another participant was thrilled to see her daughter enjoying herself and engaging with others; as she explained, "[My daughter] mostly stays at home by herself." Several community members who were present at the time, including a group of skateboarders, expressed interest in joining the game. When asked what aspects of using the touchscreen were easy, five participants mentioned zooming, three mentioned logging in or joining the game, and two wrote finding their teammates, e.g. "Finding my scooter as well as locating the other team mates. Locating the flags and team areas. Zooming in and out to locate different areas" (Participant #3). Others commented on finding themselves in the screen, finding flags, scoring, recharging, and moving around.

*Negative Comments.* Comments on what participants disliked related to the design of the game, technical issues and feedback. One participant commented that the game was too short, while another mentioned there were not enough opportunities for strategy. Having no physical markers was an issue for two participants, e.g. "Sometimes I was not clear if I had [sic] flag" (Participant #9) and "Not having a physical 'goal' landmark e.g. dot" (Participant #6). Two participants mentioned that it was difficult to see where they were on the phone, and one suggested increasing the size of the icons. Technical issues related to inaccurate capture of movement and delayed feedback. Two participants explicitly stated that there were no aspects of the game they disliked. When asked what was difficult, participants commented on the small size of the icons, zooming out, grabbing the flag, and not knowing what to do when there was a problem (non-specified): "When there was problem, I did not know what to do with it to solve the problem" (Participant #10). Two participants mentioned finding themselves on the screen. Three explicitly mentioned not encountering any difficulties.

*Suggestions.* Participants offered a number of improvements for the game. Most involved technological issues, including the desire for a larger screen, glare reduction (2 of 13), and map lag (3 of 13). Two participants requested increased game difficulty through target scores, time limits, and obstacles. Two participants desired larger icons. One participant recommended audible feedback, and another desired better feedback on flag capture. One participant suggested reducing the number of icons on the screen. Another desired the choice to attack instead of the automatic, proximity-based attacking. Two participants desired to change their names from the generic

player-number format to a more personalized identity. One participant requested more training and practice time. Another desired a way to facilitate strategy ideation.

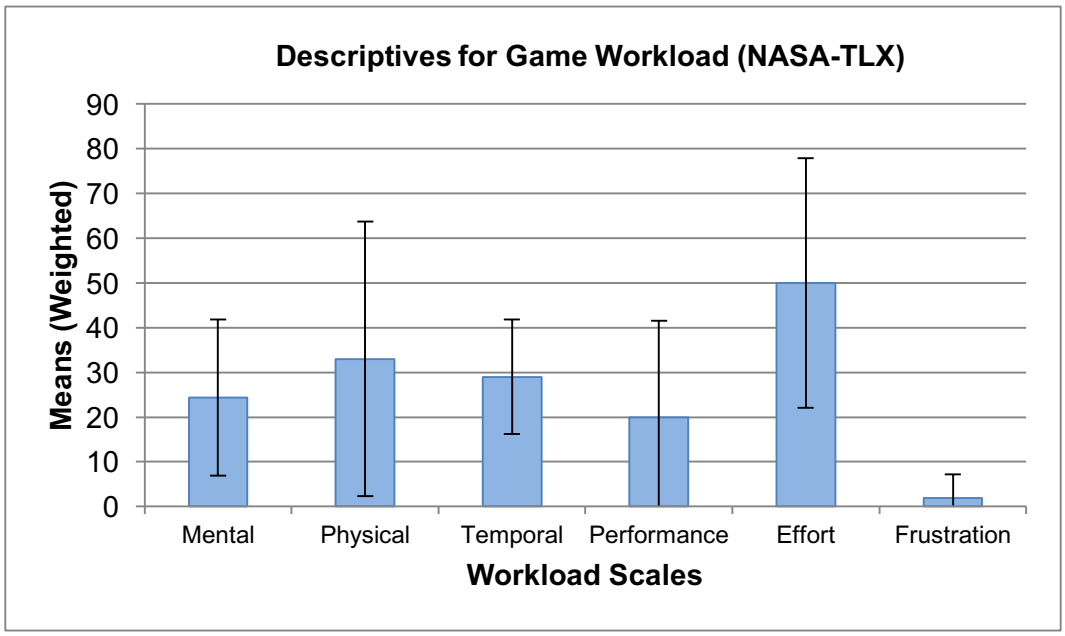


Fig. 3. Descriptives for workload (NASA-TLX) by scale (weighted). Error bars use standard deviation.

Workload data for the game that was generated using the NASA-TLX is presented in Figure 3. Workload varied across participants (N=12, M=10.55, SD=4.34). Spearman's Rank Order correlations were run to determine the relationship between workload and other factors from the questionnaire. There was a weak, positive correlation between workload and enjoyment that was not statistically significant, $r_s(12) = .22$, $p = .42$). There was a medium, negative correlation between workload and activity level that was also not statistically significant, $r_s(12) = -.42$, $p = .34$).

5.5.3. Distance Travelled. Distance scores are presented in Table II. A paired t-test was conducted to compare distance travelled in meters across two consecutive game sessions in the first study (N=8). There was a significant difference in distance between the first session (M=761.24, SD=222.73) and the second session (M=1495.27, SD=294.97); $t(7) = -5.43$, $p > .001$.

Table II. Distance scores per study and per session.

| Study | Session | Mean | Std. Dev. |
|---|---|---|---|
| One | 1 | 761.2 m | 222.7 m |
| One | 2 | 1495.3 m | 295 m |
| Two | 1 | 9144.3 m | 4261.4 m |

5.5.4. Path Data. Path data (Figures 4–6) was visualized for each player using Google Maps and recorded GPS data. The alphabetical character on each map represents a unique individual; it is matched across Figure 4 and 5, such that person (a) in Figure 4 is the same individual as person (a) in Figure 5. There is only one figure for the second study (Figure 6) because only one session was run. The colour of the paths indicates the team to which each player belongs. Simple roadmap overlays were used because the satellite images were out of date and did not match the

current environmental layout. Paths were captured to determine whether pattern of travel and route choices were associated with specific game strategies.

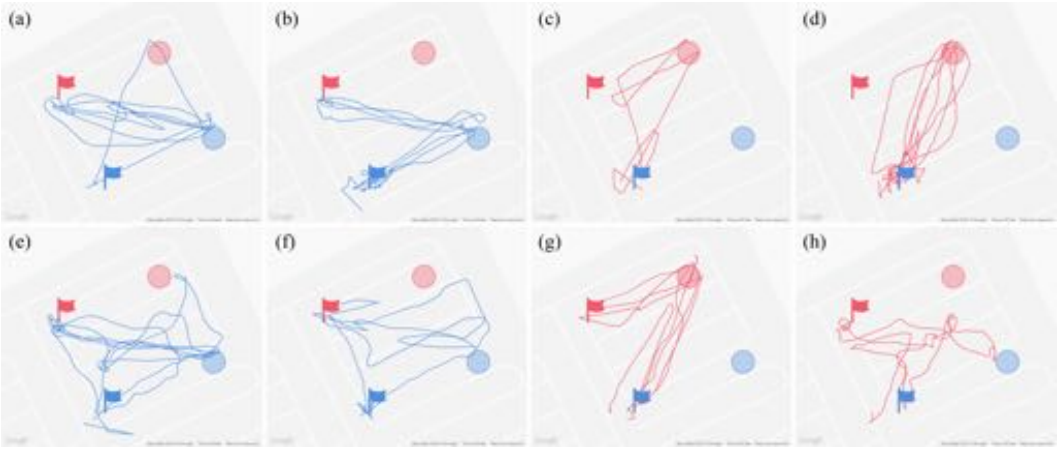


Fig. 4. Paths for individual players in the first session of the first field study. Map data ©2013 Google.

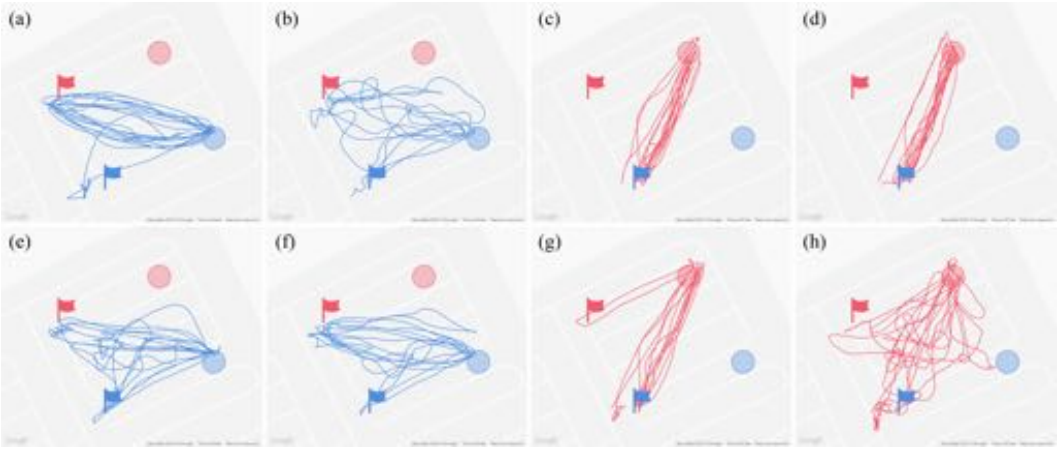


Fig. 5. Paths for individual players in second session of the first field study. Map data ©2013 Google.

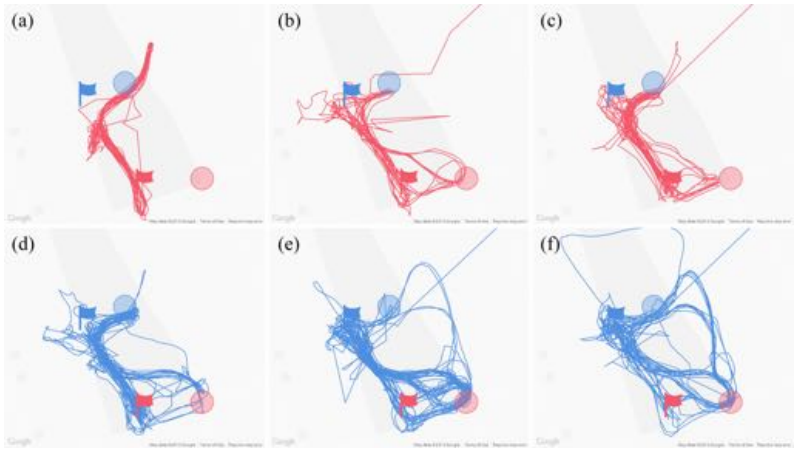


Fig. 6. Paths for individual players in the second field study. Map data ©2013 Google.

5.5.5. Post Hoc Observer Survey. The results from the survey are grouped by item and summarized using topic frequency across the group (maximum of one per participant):

*(1) Was your experience with the Mobility Games study positive or negative? Why?* All observers (N=5) reported a positive experience. Reasons included awareness of the enjoyment powered chair participants experienced (4 of 5), being involved in a practical, research-based study (2 of 5), and the lack of technical issues (2 of 5).

*(2) What was your role in the study? Describe a few of the things you did during the study:* Observers were involved as assistants during the game (4 of 5), during setup and takedown (2 of 5), during research (2 of 5), and in a technical capacity (1 of 5).

*(3) While you were helping people in powered chairs play the game, did anything about the gameplay stand out to you?* Observers noted that participants generally did not know how to play capture the flag, a game traditionally designed for people without disabilities (2 of 5). Observers also noted that there were differences in speed and strategizing between those in powered chairs and those on foot (2 of 5).

*(4) What was one thing you noticed, learned, or discovered as an observer watching participants in powered chairs play the game?* Observers noticed that participants enjoyed the game (3 of 5), the potential of the game to close the intergenerational gap, with reference to one participant who played with her grandson (2 of 5), and the advantage participants in powered chairs had over those on foot (2 of 5).

*(5) What is one comment that a participant made that stood out to you?* One observer remembered a participant saying, "I wish you could move as fast as me." Most participants could not remember a particular comment, but did remember the general enthusiasm and smiles.

*(6) Do you have any other observations you would like to share about the game or the study?* One observer commented on the intergenerational aspect, echoing the thoughts of a participant. Another observer noticed how others in the community were drawn to the game and the potential of the game to act as a community development tool that could address the stigma associated with powered chair use.

### 5.6 Discussion

While there was considerable data collected during the field studies, we have chosen to focus on three main elements—engagement, workload, and game strategies—in order to examine the impact of the game and its gameplay on the target users: adults using powered chairs. We complement this analysis with a discussion of key findings from the post hoc observer study.

5.6.1. Engagement. Overall, self-reports indicate a high level of engagement with the game. Subjective enjoyment and activity levels were high. The GEQ scores follow the expected pattern, with low scores reported for absorption and flow (which are generally harder modes of engagement to achieve) and high scores reported for presence and immersion (which are generally easier modes of engagement to achieve). Additionally, the GEQ was developed for people who are stationary game players that do not need to be concerned with either physical movement or the consequences of being tired. People with disabilities in general are more aware of becoming tired as well as the time they need to spend on each task [Kinne et al. 2004]. Specifically, the limitations of needing to pre-book transportation services and powered chair battery life impose time restrictions that are not considered in the GEQ questions related to time. Becoming fatigued has potential safety concerns that may cause people to resist

being absorbed in any activity. This is supported by how participants answered the non-GEQ engagement questions we added: not one person reported being bored or wanting to be doing something else. Participant comments such as "I liked going to collect the flags and protecting my team mates" (Participant #3) and "I like stealing the flag from other people" (Participant #8) suggest that they enjoyed the primary goals of the game. This matches what was expected based on our game's genre and participants' preferred game genres: puzzle and strategy. Using terminology such as "stealing" and "protecting" suggest that participants embodied the gameplay concepts and roles. However, observers noted that some participants may have needed more help with the game: "players might need more help with team work and strategy planning" (Observer #2) and "[some participants not knowing how to play the game] makes sense of course, its [sic] a game people who are abled-bodied grow up playing" (Observer #3). The significant difference in distance travelled for participants in the first study may also indicate increased engagement through increased activity in the game or that the parking lot covered a larger area than the park. Participant comments such "getting to run around fast pace" (Participant #10) and "moving around. Being on a team. Having a goal" (Participant #7) suggest that players liked the non-stationary aspects of the gameplay. As Observer #1 noted, "there was always movement, and the participants seemed actively engaged with each other throughout the game."

5.6.2. Workload (NASA-TLX). Correlations between game workload and other factors revealed no significant effects, indicating a high level of variability among participants. As such, interpreting these results must be done cautiously. The weak, positive correlation between game workload and enjoyment suggests that enjoyment was greater for those who experienced greater game workload. This result makes sense given that games are generally meant to be cognitively stimulating; in the case of *PTP,* strategizing and quick thinking were important aspects of enjoyment deliberatively designed into the game. Another way of understanding this result is with respect to flow theory [Csikszentmihalyi 1991]. Our findings provide initial support for the notion that sufficient challenge, given an individual's relative abilities, is correlated with the flow state, an optimal experiential state between anxiety (or frustration) and boredom. Even so, some participants reported a desire for greater challenge and more complex gameplay (e.g. more variables, such as points for strategy, and constraints, such as time limits). For example, Participant #7 wanted "more rounds—more strategy. Bit more complexity—add prevention points and reason to defend [the home base]." Participant #1 wrote: "The gameplay itself is pretty good, but add more difficulty. E.g. more obstacles or a time limit," while Participant #3 echoed this sentiment, requesting "… a target score … to make the game more challenging." In contrast, observers noted that people with vision or cognitive impairments experienced difficulty catching up with other players. The medium, negative correlation between game workload and activity level indicates that the greater the workload, the lower the activity level. Participant commentary suggests that certain aspects of the smartphone interface—namely, the size of the screen and relative size of the icons—could have distracted participants from primary game tasks. Cognitive workload was slightly disruptive to level of activity for some participants. Commentary by Observer #2 supports this: "[some participants] might need more help with team work and strategy planning."

5.6.3. Path Data: Strategies. Strategies are a key feature of CTF-style games. The three main strategies designed into our game are: a "runner" strategy, where the

player focuses on moving back-and-forth between the home and enemy bases with the intent of bringing back their team's flag, finding the shortest or most direct route to achieve that goal, and providing habituation opportunities; a "protector" strategy, where the player's goal is to prevent the flag their team is protecting from being taken; and an "interceptor" strategy, where the player attempts to intercept enemy players who are in the process of bringing a captured flag back to their home base. The latter two strategies add a congestion factor to the gameplay that prevents others from taking the most direct route. Further, players cannot use these strategies at the same time and must switch between them if they choose to do so. Indeed, Observer #1 noted that they were actively engaged in making decisions about strategy-making: "… participants used the virtual representations of players on the game map to organize their real world selves." Note that it is difficult to distinguish between the "interceptor" and "protector" strategies because they look similar in the path data; triangulation of data and more sophisticated data analysis tools for path data are needed.

One way of empirically determining how players negotiated strategies is by comparing visualized path data. Figures 4–5 show the variability of each player's path regardless of team. In general, we suggest that the greater the variability in path, the less likely that the player was invoking one specific strategy or attempting to use the shortest route. As is common in CTF games, there is a trade-off between being the fastest to achieve the target goal (i.e., capturing the opposing team's flag) and avoiding or interfering with the path(s) of player(s) on the opposing team to prevent capture of one's own team flag. Variability could therefore suggest a strategy of avoiding the congestion mounted by the opposing team players, resulting in players employing different strategies (or route choices) over time.

In the first session of the first study (Figure 4), the line patterns demonstrated by players (a), (c), and (d) suggest that one strategy, the "runner" strategy, was almost exclusively employed. The paths of players (b) and (g) show evidence of a combination of all three strategies, with path lines between the home and opposing team's flag (the "runner" strategy) and the home and their team's flag (the "protector" and "interceptor" strategies). The paths of players (e), (f), and (h) are less clear; evidence for all three paths is present, suggesting that no one strategy was adopted for the duration of the session. Variation in the first session may be due to participants experimenting with and learning the rules of the game or adopting different strategies a needed or requested by their teammates.

Comparing path data in the first session to the second session, which featured a greater amount of path data in terms of distance travelled (a statistically significant difference), suggests that most participants became dedicated to a particular strategy. Participant (a) is a case in point. Path lines for this participant across sessions (Figure 7) show less variation and almost an exclusive path to and from the home and opposing team's flag (the "runner" strategy in practice).

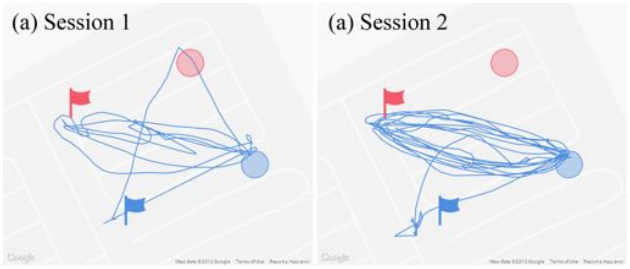


Fig. 7. Path data from the first and second sessions for participant (a) from the first study. Map data ©2013 Google.

Some path data shows a greater degree of variation between sessions in the first study. For instance, a comparison of the path data between sessions for participant (b) (Figure 8) shows a greater degree of variability in the second session. The strategies used across both sessions appear to be the same—a combination of "runner" and "protector" or "interceptor"—but the greater variability in the second session may indicate either a learning effect relevant to the "interceptor" strategy—spreading out to intercept the other team—or greater team communication, e.g. another team member asking this player for help, involving a change from one strategy to another.

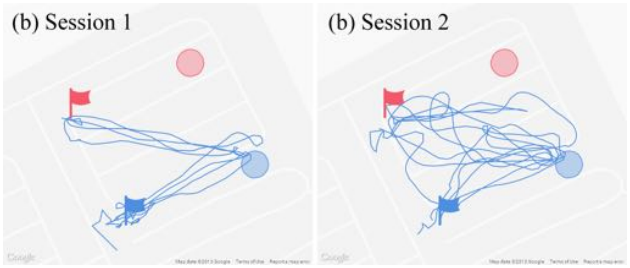


Fig. 8. Path data from the first and second sessions for participant (b) from the first study. Map data ©2013 Google.

A second comparison of path data between sessions for one of the players whose strategies were unclear (Figure 9) suggests a possible learning effect with greater distance travelled and increased path variety. In the first session, the player is exploring strategies while traversing physical territory. In the second session, the player appears to have adopted the "runner" strategy (with many path lines going between the home base and the opposing team's flag) while also periodically adopting the "protector" and/or "interceptor" strategies (note the lines moving towards their own team's flag and the opposing team's home base).

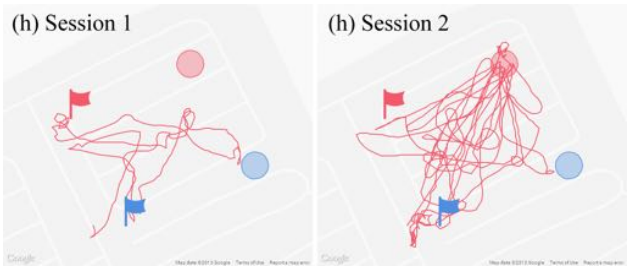


Fig. 9. Path data from the first and second sessions for participant (h) from the first study. Map data ©2013 Google.

The second study took place in a park area featuring paved walkways but also shrubbery, trees, and other foliage of which some participants took advantage. The blue team, players (d), (e) and (f), deviated from the main path by following a path along the right side of the park, suggesting evasive manoeuvres (Figure 6).

5.6.4. Post Hoc Observations. The observer survey responses indicate three key factors that complement the findings from the field studies:

*Intergenerational Play.* In the second study, a grandmother and grandson played together. According to observers, the grandson helped his grandmother learn and play the game. In the words of Observer #2, games like *PTP* have the potential to "close the intergenerational gap" that people of all ages often believe exists. Future work can explore how to design inclusive mixed reality games for people of all ages to play together simultaneously.

*Mixed Ability Play.* The nature of the setup, with powered chair users assisted by observing researchers on foot, resulted in mixed ability play, or play that involves a mixture of abilities, in this case running on foot and powered chair-enabled travel. In the words of Observer #5: "[The] game is interesting and fun for people who aren't in power wheelchairs too." Observers noted the advantage those in powered chairs had over their on foot counterparts: "those of us running were at a serious disadvantage" (Observer #3). Observer #4 noted the potential for harnessing the relative advantages of both modes of mobility: "It was interesting to see the balance of power in the game between those [in powered chairs] and those on foot. It could make for some interesting strategizing."

*Community Engagement.* The use of everyday environments alerted us to the potential of community engagement. Observers noted that people who happened to be in the surrounding area at the time of the study, including teenagers on skateboards, expressed interest in participating in the game. As Observer #3 noted, "I was particularly interested in the way the games drew in 'others' in the community—not only to observe but attracted them [sic] to want to 'try' it and also play." Due to ethics restrictions, we could not oblige these interested bystanders, but their interest suggests that the game may be used as a platform for social and/or civic engagement: "[I] see this as a great community development builder that has great potential for addressing issues of stigma also" (Observer #3).

5.6.5. Discussion Summary. Overall, findings show that participants found the game to be fun, social, and accessible, and engaged with the game in a variety of ways that were made apparent through a review of the path data. Participants experienced high levels of engagement; additionally, we were able to account for the limitations of the GEQ as applied to powered chair users through additional, carefully considered engagement questions. Engagement was not affected even when participants had to learn how to play the game. Individual variation prevented us from reaching a consensus about the effect of the gameplay on workload; participant and observer commentary supports the notion that some players found the game more difficult than others, and vice versa. Movement emerged as a key factor of engagement that may increase over the course of the game and/or be affected by the size of the physical environment. This was made especially salient by the path data in terms of: differences over time (greater movement over time), between environments (greater variability in path data given environmental features), and across participants (learning and experimentation, as well as commitment to a strategy over time). Finally, observer commentary identified three complementary factors that arose as a

result of the inclusive, social game design and everyday setting: intergenerational play for multi-age inclusivity and enrichment; mixed ability play that harnesses and supports the abilities of those with and without motor impairments and other disabilities; and community engagement through integration or enactment at public, open community sites. Taken together, these finding suggest several design implications, guidelines, and trajectories for future research, which we discuss in turn below.

### 5.7 Implications for Design

The path data suggests that players use a variety of strategies to pursue game goals given the location of relevant game elements in physical and virtual space. Further, commentary by participants about the gameplay indicate that more challenging gameplay is desired. This matches our findings on path trajectories, which suggest that most participants settled into one strategy during the game. One way that greater challenge and variety in strategy can be accomplished is by choosing a more complex physical space in which to play the game; for example, a space that contains pylons, shrubbery, and other physical landscape features placed such that they impede the paths demonstrated by visualized data and perhaps even players' sight distance. Additionally, the flag locations and home territories—both of which are virtual—could dynamically change, forcing players to adapt to unexpected paths. Games that encourage team play seem to be enjoyable and positive for this cohort and should be considered in future game development for this user group. Finally, given most participants' preference for practice as a method of learning how to use a powered chair and the nature of the gameplay we explored in this study, such a game may be used as an enjoyable, engaging alternative to traditional training and way to practice with their mobility aid.

### 5.8 Guidelines for Includifying Traditional Games for Power Mobility in Mixed Reality

The following initial set of guidelines was developed from a combination of three key sources: the protocols and findings from our study; findings from previous work on game accessibility; and the work of the includification movement [Barlet and Spohn 2012], which provides an extendable framework centred on how to make games inclusive. Our goal was to expand on the existing general guidelines for games and mobility device users to focus on the specific cases of mixed reality games and powered chair users. Future work will aim to refine and validate these guidelines for a variety of game genres, environments, and play styles.

5.8.1. Controls. Game controls should not monopolize the driving controls: players should be able to switch between both and focus on either as needed. Echoing Kane *et al.* [2009], alternative configurations and/or remapped keys/buttons/gestures may be required to accommodate people in powered chairs who have non-mobility impairments, such as muscle weakness in the hands, or who already use alternative input controls, such as mouth sticks used by quadriplegics. As in the case of our design, these should be developed as a layer or mode that may be added or removed as needed. For instance, we provided a *Tecla Shield* for anyone who needed an alternative to touch-based interaction. Third party software and hardware should be supported. Mounts, such as the *Tecla Arm* used in our study, should be provided for handheld game interfaces, such as smartphones and tablets, for comfort and to reduce the risk of losing the handheld during gameplay.

5.8.2. Display. As noted by our participants and also found by Kane *et al.* [2009], virtual game content presented through a display should be resizable: content should automatically be resized in a responsive fashion based on the display size and any default preferences set by the user, and it should also be possible for the user to manually resize the content, e.g. pinching gestures to resize a map, as needed. However, the default size of content should be sized to fit the expected needs of participants ahead of time. Although most participants used a computer and/or handheld technology regularly and were experienced with touch-based interfaces like the ones used in the study, some participants did not like having to resize the screen. As in our study, some initial configuration may be necessary to find the ideal orientation and placement for the display.

5.8.3. Environment. Previous work on game accessibility, e.g. Yuan et al. [2011], has not explicitly considered the physical environment, most likely because the vast majority of digital games have not, until recently, made use of the physical environment. In a mixed reality setting, the physical environment needs to be made accessible for powered chairs. In our case, this was initially a matter of ethics adherence; however, testing during the development phase demonstrated the real need of a baseline barrier- and hazard-free space. For instance, people in powered chairs may be able to dodge litter and potholes but may not easily move from sidewalk to road or travel through narrow passageways, between parked vehicles, or through environmental features like trees, fences, and statues. In our study, we used safety tape and pylons to cordon off unsafe areas. If possible, render or recreate features in the physical environment in the virtual space, i.e. display these features through the tablet to ensure that the player does not miss this information.

5.8.4. Mechanics. Use of the powered chair should be accommodated in the design of the game, either by not requiring mobility or allowing the player to complete operation as well as game tasks without one monopolizing or interfering with the other. For instance, we discouraged players from getting too close by adding a "health drop" mechanic that was triggered based on proximity to another player and resulted in a negative outcome—the inability to hold the virtual flag (to complete the main game task). Difficulty level should be adaptive based on two factors: (a) the particular chair's abilities, and (b) the gaming experience of participants. Players with powered chairs that have a speed cap can be given a head start to compete on fair terms with those who have faster chairs. The use of assists should be considered to account for varying levels of precision in powered chair navigation, as well as potential technical issues, such as the lack of GPS precision in our study. However, the difficulty of the game should be considered separately from the powered chair and reflect the gaming experience of participants. In our study, many participants reported having a lot of gaming experience and finding the game to be too easy, meaning that we only met requirement (a) for difficulty, and suggesting that the next version of the game—beyond accounting for differing configurations among chairs—would need to be more challenging.

5.8.5. Multimodality. Participant commentary suggests that multimodality—presenting related information through more than one sensory channel—should be supported for those with differing abilities and/or preferences. For instance, Participant #7 requested "audible signals" in addition to visual and embodied feedback in the game. Presenting the same information through different sensory channels in a way that is complementary (each builds off the strength of the other and makes up for the weaknesses of each) or redundant (to support different abilities

and/or preferences) is supported by multimodality theory [Bernsen 2008] and reflected in Yuan, Folmer and Harris's [2011] notion of a secondary source of stimuli to support the primary mode of information presentation.

### 5.9 Limitations

Several technical and research design issues limit this work. Technical issues include inaccurate GPS data and server lag (for instance, player positions could take a couple seconds to update). Additionally, some players were inexplicably dropped from the game. We expect these issues to be mitigated as carriers continue to refine their services and devices continue to improve. A remaining programming challenge is to dynamically render flags so that they are not placed on inaccessible areas (such as rooftops or roads) and thus preventing players from completing the objective of the game. Improvements and changes in the type of data the Google Maps API provides may help mitigate this issue in future. Research design issues include small sample size (13 participants), lack of open-ended questions to capture subjective enjoyment and engagement commentary, and a disconnect between recorded player data and the smartphone used. In future work, we plan to recruit more widely, include additional relevant questions, and ensure that participant data and smartphone pairings are recorded. The order of appearance of questionnaire instruments, notably the placement of the NASA-TLX, which measures cognitive load and could have been affected by its placement at the end of the questionnaire, was a possible limitation; future work will ensure that order-sensitive instruments will be placed accordingly. A final limitation was the modification of the environment for ethics purposes; this limitation may only be overcome by conducting observational, ethnographic research of these types of games being played in situ, which we hope is on the horizon.

### 5.10 Future Work

This work has generated a number of rich trajectories for continued research in mobile mixed reality gaming for adult powered chair users. Other disciplines have looked at virtual and physical path strategies to predict behaviour, e.g. driving in human factors research [Godthelp et al. 1984] and navigation in web environments [Mead et al. 1997]. In our work, there is some initial evidence to suggest that physical movement in a game space relates and may be predictive of game strategies. Future work can explore this notion through correlating path data with individual and team success. Illuminating the role of physical movement above and beyond exercise and realism could provide further empirical justification the use of mixed reality gaming as well as inform best practices for creating appropriate challenge in mixed reality game spaces.

Findings from the NASA-TLX workload data and GEQ results suggest a model of engagement that reflects Csikszentmihalyi's [1991] model of flow. To the best of our knowledge, no work to date has attempted to provide empirical validation of how flow theory may be used as an explanatory model of workload and game engagement data. While it is out of the scope of this project, future work could explore whether and how such data may be correlated to Csikszentmihalyi's model of flow in a gaming context. Future work could also consider other instruments, such as PENS [Ryan et al. 2006], for this purpose as well as an additional indicator of engagement.

Additionally, the audio data meant to capture in-game participant commentary and vocal expressions was too noisy for analysis. A potential workaround is to have participants return and review video data of the game in using an ex post facto cognitive walkthrough approach. However, such procedures may need to be planned

in advance. The longer the duration between the study and the return visit, the more likely pertinent information will be lost or distorted due to the limitations of human memory. Further, planning in advance potentially maximizes attrition given that adult powered chair users tend to rely on accessible transit for getting around, which requires advance booking and additional fees.

The set of guidelines we developed for recreating inclusive versions of traditional games designed for people without disabilities using technology is a first step and needs to be refined and validated through further game translations and research studies. This is a major goal actively being worked on in the overarching *Mobility Games* project. A related topic is to explore similar user groups, such as users of non-powered chairs.

Finally, our work showed initial support for the use of mixed reality gameplay in everyday spaces as a means of social engagement—with the community, with people that have differing abilities, and with other age groups—for adult powered chair users. Future work could explore the impact of such a system on the social world and leisure behaviour of this user group in more detail.

## 6. CONCLUSIONS

A smartphone-based mixed reality game, *PTP* was developed based on a popular genre of game, capture-the-flag (CTF), and evaluated with adult powered chair users. This paper presented evidence that the game was fun to play and that team-based gameplay was a desirable quality. Path data revealed a variety of strategies employed by participants to carry out game tasks. The first field study, which had two sessions, indicated that most participants underwent a change in game strategy development, where they moved from a more exploratory approach to a smaller set of committed strategies. Observer commentary supports these findings and suggests expansion of the platform for the purposes of intergenerational play, mixed ability play, and community engagement. Overall, our findings provide initial empirical evidence of the success of mixed reality gameplay for the target user group.

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