Pers Ubiquit Comput (2015) 19:495–508
DOI 10.1007/s00779-015-0845-0

ORIGINAL ARTICLE

Expanding social mobile games beyond the device screen

Misha Sra[1] · **Chris Schmandt**[1]

Received: 20 November 2014 / Accepted: 3 April 2015 / Published online: 23 May 2015
© Springer-Verlag London 2015

Abstract Emerging pervasive games use sensors, graphics and networking technologies to provide immersive game experiences integrated with the real world. Existing pervasive games commonly rely on a device screen for providing game-related information, while overlooking opportunities to include new types of contextual interactions like jumping, a punching gesture, or even voice to be used as game inputs. We present the design of Spellbound, a physical mobile team-based game, to help contribute to our understanding of how we can design pervasive games that aim to nurture a spirit of togetherness. We also briefly touch upon how togetherness and playfulness can transform physical movement into a desirable activity in the user evaluation section. Spellbound is an outdoor pervasive team-based physical game. It takes advantage of the above-mentioned opportunities and integrates real-world actions like jumping and spinning with a virtual world. It also replaces touch-based input with voice interaction and provides glanceable and haptic feedback using custom hardware in the true spirit of social play characteristic of traditional children's games. We believe Spellbound is a form of digital outdoor gaming that anchors enjoyment on physical action, social interaction, and tangible feedback. Spellbound was well received in user evaluation playtests which confirmed that the main design objective of enhancing a sense of togetherness was largely met.

✉ Misha Sra
sra@media.mit.edu

Chris Schmandt
geek@media.mit.edu

[1] MIT Media Lab, Cambridge, MA, USA

Keywords Whole-body gestures · Mobile game · Wearable · Team · Speech recognition · Social play · Kinesthetic interaction

1 Introduction

Technology has become deeply intertwined with our everyday social connection and that means interactions and experiences (positive or negative) are now shared through digital channels. Many have argued that this transition to social media has led to increased social isolation—people spend more time on and with their devices than with other people [20]. In the absence of technological augmentation, it is shared physical experiences of one another (e.g., taking a walk together or playing *Tag* with friends) and the world around us that connects us. This leads to the question of how can the social and emotional palette of technology design be broadened to better support human beings as we feel, express, and interact with each other [22].

Togetherness and camaraderie have long been central to the discourse around play and games. Play theorist Brian Sutton-Smith identifies them as "rhetorics of identity" and calls social play a "form of bonding" where camaraderie and togetherness are central to the experience [44]. These are well depicted in traditional children's games played with commonly available equipment often involving physical interaction between players, e.g., Freeze Tag or Duck Duck Goose. Through physicality and laughter, play engenders a special form of togetherness: "face-to-face contact and the interaction between 'I' and 'you'" [14]. This interaction facilitated by game rules is the inspiration behind our goal to create a mobile game that eschews the mobile device's screen as the primary channel of interaction and communication. Instead, we designed our system

to rely on user knowledge of the real world and face-to-face communication to enhance the sense of collective experience. This combination of a digital game with features from traditional games offers personalization of game characters, multiple game levels, involved storytelling, power-ups that are not physically possible, and a variety of game settings.

Modern digital games provide a variety of immersive and social experiences across a wide range of genres from massively multiplayer role-playing games (MMORPGs) to team-based shooters. Worldwide, we now spend more than 3 billion hours a week gaming [35]. This enthusiasm for games can be leveraged to reinvent how we do anything from how we educate ourselves to how we attend to our physical, mental, and social well-being. With this in mind, we developed Spellbound, a competitive and collaborative outdoor mobile game played in teams of three, with custom hardware that frees players from the constraints of their devices' touch screens. Our design serves as an example system where playing together can lead to increased engagement and fun and serve as a facilitator for socializing. Admittedly, designing a new game that is both accessible and appealing is no trivial task especially given the challenges of the virtual/physical crossover. Nevertheless, the popularity of games speaks to their capacity to attract a diverse group of people making them an interesting platform for studying and designing social interactions. Salen and Zimmerman [41] view the relationships between elements in a game system as social relationships in which the players participate by communicating via game play. In such a system, a game's design can contribute to the emergence of social play [41] where embodied interactions facilitate social aspects [13].

Spellbound has the following design elements to help facilitate social play: First, players in each team interact with the virtual game, in groups of two or three, through synchronized (in place not time) full-body physical interactions like jumping and spinning, merging real-world activity beyond walking or running with virtual world consequences. We aimed at user-independent gesture recognition, with no training phase involved and our system can recognize jumping, spinning, running, and walking. For example, to demolish a virtual "enemy hideout," players have to physically jump on it at a specific physical location, or to extract a virtual "power core" from the earth, players have to physically spin around to virtually drill it out of the ground. Second, players move about freely in the outdoor play space maintaining contact with their team members by talking to them and contact with the non-player characters (NPCs) in the fantasy world by speaking into the mobile device's microphone. Third, information from the game is communicated tangibly to the players through custom-designed wristbands and armbands. For example, when a team completes a quest, the other team is notified of it through their wristband which vibrates and an LED corresponding to that specific quest lights up. Another example of non-visual tactile communication occurs when a player is searching for the hidden virtual "power core." Armbands guide their search by tugging their left or right sleeve to indicate direction. Reducing dependence on the mobile screen and bringing game information into the real world through haptic and glanceable devices add a new layer of immersion and freedom with hands-free play.

In Spellbound, quests are diverse with respect to the physical interaction needed, technologies used, involvement of bystanders or passers-by, and team effort required. We introduced this diversity, firstly, to cater to different play styles (lead vs follow, team play vs solo) as well as to explore different types of social engagement that is possible while playing outdoors, namely interactions within a team, between two teams, and with other people who are part of the outdoor public space where the game is played. Additionally, through quest and custom hardware design, we wanted the game to serve as a test bed for understanding the impact of different scenarios and haptic feedback on social interaction, engagement, and overall experience. The main research contributions of our work are the following:

- The game uses voice input for interaction with virtual characters using the Google Speech Input API. This design approach allows users to keep their eyes and focus on the world around them while still receiving directions and feedback from the game in response to their actions. Furthermore, we do not display player locations on a game map to encourage players to observe their surroundings and other players, as they would in a game of *Tag*, for enhancing social engagement.
- The wearable hardware (armbands and wristbands) provides directional guidance and information about the game state through haptics and LEDs, obviating the need for players to constantly consult their mobile device for current game state. The screen can be difficult to view in bright daylight and not readable while jumping or running and can take focus away from the physical environment; we designed haptic feedback to allow players to keep their focus on the world and other players around them, much like in a traditional children's game or a sport activity. This can lead to smoother flow of gameplay which in turn can bring forth an enhanced sense of togetherness, socialization, and enjoyment.
- The design supports active engagement through team cooperation required for the completion of quests, i.e.,

synchronized jumping or spinning near a virtual item's location in the real world. Additionally, passers-by or spectators are also made part of the game through a quest.
- It is a fast-paced game with approximately 10 min of play time per session. This makes it easy to spontaneously include physical/social activity in your day during a short break.
- We do not include a digital communication channel in the game to promote communication in the real world. We also wanted to reduce screen time and encourage face-to-face interactions for increasing social engagement. The concept works because the game is played in real time in a play space that is not larger than a football field.
- Our game design takes into account the localization uncertainty that is inevitable when using GPS, WLAN, and Cell-ID such that no action in the game requires accurate player location. We use an area of effect (AoE) model where players can interact with all virtual elements within a predetermined radius which was determined through iterative playtesting. Our work is entirely based on open-source platforms and tools.

We proceed by providing related work in Sect. 2 that has inspired us. Then, we present details on the design process, main design concepts, and implementation issues in Sect. 3 followed by an overview of actual gameplay and quest details in Sect. 4. Section 5 talks about the evaluation methodology and our observations, and user feedback and survey results are presented in Sect. 6. Section 7 highlights and discusses two main themes that contribute to our goal of enhancing togetherness. The main findings drawn from our discussion are presented in Sect. 8. Finally, Sect. 9 concludes the article and draws directions for future work.

2 Related work

Location-based games have been around for over a decade. Many research prototypes [4, 11, 12, 24, 36, 46] as well as some commercial games, like *Ingress* [28] and *Zombies, Run!* [47], use the player's location as data input for the game. In these games, players equipped with mobile devices move through the outdoor game world while sensors attempt to capture contextual information based on their location [3, 9] to provide a richer experience. Pervasive gaming has evolved with the emergence of mobile devices equipped with GPS, 4G LTE, cameras, and a host of sensors (accelerometer, gyroscope, magnetometer, heart rate, light, proximity, etc) leading to the development of complex and large-scale games [28, 47]. Most existing prototypes are location-aware and use data connectivity for communicating with a central game server as well as with other players [25] while depending on the device screen as an input and output channel. Spellbound's contribution to the research theme of pervasive immersive games is replacing the device screen with haptic wearable devices for investigating the impact on social engagement and immersion.

Digitally meditated games that encourage physical activity and social play form "an emerging genre in which traditional, real-world games are augmented with computing functionality, or, depending on the perspective, purely virtual computer entertainment is brought back to the real world" [33]. These games can have positive implications for health concerns such as obesity [18] by encouraging players to be more active. They can offer physical, social, and mental health benefits [17, 23, 40] and are more enjoyable than traditional exercise [32]. We build upon social digital play in movement-based games [16] by situating our work in the context of an active team-based competitive game played in an outdoor public space. Games that encourage activity are also be apt for encouraging social play [15, 43, 49] and even attract wider user participation [6, 29]. With qualitative studies, research has shown that the physicality of game artifacts can contribute to and facilitate social play [2, 39]. Though technically the wristbands worn by players in Spellbound are not game artifacts like a ball might be, we believe that, because they communicate information about the state of progress of the other team, they contribute to the sense of togetherness more viscerally than viewing the same information on the smartphone screen. Table 1 shows the main input and output mechanics of some related work and highlights their unique features.

We chose haptic feedback as an important channel for conveying information because human skin makes a good communication medium "as it combines important aspects of the eye and the ear, with high acuity in both space and time" [19]. The sensations of vibration, temperature, pain, and indentation provide an effective communication channel [8] and a powerful method of receiving information. Tan investigated the use of a 3×3 grid of stimulators on a user's back to provide navigation information [45]. Other relevant work has taken place in aircraft cockpits to provide pilots with navigation information [48]. These examples successfully use simple tactile cues for direction similar to the armbands worn by players in Spellbound. The wristbands, however, do not provide any directional information but instead make players aware of the current quest progress of the opposite team, through vibrating motors and LEDs.

Prior work in pervasive and urban games has explored elements of collocated interaction such as "live" orchestration from a control room through digital communication [12, 30], collaboration between people on the ground and

Table 1 Main features of select related work and Spellbound

Game	Input	Output	Unique features
CYSMN? [4]	Location	Device screen	
EM II [30]	Location	Device screen, large touch screens	Dual mode (mobile, stationary), device exchange, temperature and wind speed data as input, augmented reality
Hot Potato [10]	Location, buttons	LEDs	Hand gestures, proximity, device/player orientation
Human Pacman [11]	Location, physical objects, shoulder tapping	HMD	Physical interactions
Ingress [28]	Location	Device screen	MMO, live events
REXplorer [1]	Location, hand gestures	Device screen	Hand gestures
Spellbound	Location, proximity, speech recognition, actions like jumping, spinning	Custom hardware (LEDs, vibration), audio, device screen	Glanceable and haptic hardware devices, voice input, full-body gestures, synchronized input actions: jumping, spinning
TimeWarp [21]	Location	Device screen	Location-based augmented reality, no time limit
Zombies, Run! [47]	Location	Audio	Scripted stories

online [4], giving and following instructions in teams [37], and successfully merging physical and virtual play [4, 11, 46]. *Can You See Me Now?* [4] was a pioneering catch game of collaboration where online players were chased through a virtual model of a city by players on the street. *Zombies, Run!* [47], an immersive running game, and *Growl Patrol* [27], an animal rescue game, both use audio as the primary communication medium. *Human Pacman* [11] was a milestone pervasive game where the movement of players within the game space required the use of devices stored and carried by players in a backpack. Players were enrolled as pacmen, helpers, and ghosts and carried head-mounted displays, where augmented reality game content was projected. Players interacted with physical objects as well as with each other in this novel social activity designed to mimic games in the physical world using our sense of space and spatial relations [11]. In general, several works focus on the technical issues raised by specific games while some try to generalize issues regarding the design of pervasive games overall [11] or evaluate how people perceive and play a pervasive games [42].

REXplorer is designed for tourists who are given a "magic wand," a camera-equipped smartphone, and are asked to cast a spell by waving their hand in air, a site-specific gesture recognized by the device [1]. *Foxhunt* [36] is an augmentation of the playground game of *Tag* that places several players in a large field using location-aware mobile phones for hunting virtual foxes. Most of these games do not have any direct social interaction that takes advantage of co-presence of players, and they depend on the device screen for input and feedback. Spellbound is inspired by these pioneering works. A key difference of Spellbound's design from existing work is that it enhances real-time interactions between players through cooperative full-body actions for completing quests. To the best of our knowledge, prior work that has used gestural interaction for input in a pervasive game has not employed full-body gestures similar to those used for interacting with Kinect or Wii games in an outdoor context. Additionally, it uses custom hardware for providing information that keeps focus on other players and interactions with them by removing the need for consulting the device screen frequently during play. All of the works mentioned above differ from our vision, at least in the sense of their goals; we envision games that involve teams of multiple players and focus on fast-paced synchronized physical activity, full-body physical input, voice input, and screen-less output, whereas in the majority of the existing approaches, intense physical activity and screen-less feedback are not options.

Much existing research in pervasive games explores the relationship between the player and the game where players are collocated in a relatively small physical space. Movement-based digital games which respond to bodily input [38, 40] have already found commercial success like Dance Dance Revolution[1] which is based on players synchronizing their movements with on screen visuals in time with music or Kinect Sports Rivals[2] where player avatars are a scanned likeness of them and body movements are used to mimic actions in real-world or made-up sports. These games foster sociality through spectatorship as one or two players engage in interactions with virtual avatars on a digital screen while others watch or wait their turn. We know movement can enable social digital play [6, 23].

[1] DDR. http://www.ddrgame.com.

[2] KSR. www.xbox.com/en-US/xbox-one/games/kinect-sports-rivals.

However, we believe increasing players' social engagement in a movement-based game by introducing haptic feedback needs further investigation and Spellbound aims at addressing this issue. To expand on the question posed by Garner et al. [16] and through the design of Spellbound, we are motivated to answer the research question: How do screen-less technologies support social interaction in play around location and movement in an outdoor public space?

3 System design and gameplay

For a synchronous multiplayer game, it is essential that all players in a team receive the same exact game state at all times. Therefore, Spellbound features a centralized client–server architecture that is made of three main entities: a game server (Parse[3] cloud platform), game clients (Android smartphones), and custom wearables (wristbands and armbands). Data between the server and smartphones are transmitted over wireless technology. The wearables communicate with the player's smartphone through a Bluetooth-connected IOIO[4] board for accessing game state in real time. Communication between the player and the virtual game happens through physical actions, voice-based input, audio output, and haptic and glanceable feedback. All these mechanisms are employed to create a hands-free social play experience.

3.1 Design process

While designing the game, in addition to fun technical feasibility, context, interactivity, narrative, and experience must all be considered if we want players to return and play frequently [13]. We developed the game using an iterative prototype-design approach with graduate students and faculty as design informants, building upon previously published guidelines [26]. We focused as much on engineering the system as on creating the experience. The design work resided in finding a balance between creating a system of rules and creating conditions necessary for players to approach the game with a certain degree of self-abandon and humor. We started by looking at playground games that involved social and physical interaction between players and chose a subset of games (Cops and Robbers, Hide and Seek, Capture the Flag, Chinese Jump Rope) to inspire the design of Spellbound. Salient elements from each game like team play, hidden treasure, competition, movement, and cooperation helped gave us a foundation for Spellbound.

To conceive the rules, storyline, progress, and flow, an initial board game prototype was designed and tested with six players. During playtesting, we realized that a board game was not the best way to prototype an outdoor physical game. However, it helped us understand game elements like balancing roles and abilities, incorporating elements of chance, considering communication and coordination between players, and exploring complexity. These were incorporated into the next iteration of the paper prototype that was playtested outdoors as it better simulated the final gameplay experience.

Valuable lessons learned from the outdoor paper prototype playtest were: (1) acting playfully in a public space is awkward but compelling (performative), (2) 10–15 min of continuous running, jumping, and other physical activity is an acceptable amount of physical activity (active), (3) searching for hidden virtual items by talking to the phone feels natural and elicits communication between team members (hidden), and (4) its not complex game mechanics but teamwork and competition that make play fun (social). The biggest challenge in designing Spellbound was combining these experience elements with game elements (multiplayer, mobile, location, voice, narrative) seamlessly to create a novel and fun experience.

3.2 Design features

3.2.1 Interaction and cooperation

The players are assigned to two opposing teams, namely Aliens and Humans. Both teams receive three quests each, and the team that completes them first wins. Locations of virtual elements (characters, items) are dynamically mapped to physical locations in a preselected outdoor play area, and player proximity is used to initiate action-based interactions with the virtual elements. A quest is considered complete when the game registers the action-based interactions (jumps, spins, run) by recording and processing sensor data from the player's smartphone. Narrative is based on team affiliation and is different for both. In the design of quests for Spellbound, we attempt to include the three elements of fantasy, challenge, and curiosity that research shows contribute to fun in computer games and intrinsically motivate players [34]. Additionally, the quests are designed such that completing them requires participation by two or more team members for promoting cooperation and interaction between the users. An extended version (not discussed in this paper) of Spellbound includes a competitive "bug hunt" that allows players to "freeze/unfreeze" each other using physical touch interaction found in traditional games like Tag or Hide and Seek adding the tangible sense of touch to the fantasy domain of gameplay.

[3] https://parse.com.

[4] https://github.com/ytai/ioio/wiki.

Elements of physicality and teamwork are emphasized to create a new experience of gaming in public spaces. We consider kinesics, haptics, and proxemics to design social relationships between players and the audience in an outdoor public space. Physical actions performed by players on the same team in unison like jumping and spinning are used to create focus on togetherness, activity, and location in the physical space. A player's focus shifts only between themselves, their teammates, and the audience during gameplay, leading to more engagement with each other and their real-world setting.

Without a digital communication medium, players need to talk to each other for coordinating gameplay. For example, in the *Find* quest, one player may locate the hidden virtual item but all team members need to converge upon that physical location to spin together for completing the quest. Like a playground game, players interact over small and large distances to gauge information from verbal and nonverbal cues. Talking with team members provides an opportunity to learn, strategize, negotiate, cooperate, and take actions for making progress in the game. Additionally, removing player location information from the digital game map causes players to pay attention to gameplay around them. They can plan their next course of action by observing the other team's location and movements in physical space and use the wristband to gauge their game progress. Using wearable devices for glanceable and haptic feedback also influences the degree of social interaction between players and smooth flow of play by reducing dependence on the digital screen for information. Playing over a larger space necessitates communication and coordination, while reducing dependence on the device screen takes advantage of the co-presence of players in the physical space encouraging a broad range of social interactions.

3.2.2 Physical input

Whole-body gestures can provide a natural and promising user interface modality for games that are looking to increase user activity and incorporate other mechanics beyond currently used walking and running. Unlike touch screen-based interaction, whole-body gestures can simplify on-the-move interaction by reducing the need to concentrate on the device screen in bright daylight as well as make the interaction feel more naturally suited to the quest task, e.g., squishing bugs by jumping on them feels more natural than tapping on them with a finger. In Spellbound, the primary interaction mechanism with the virtual game is whole-body gestures like jumping and spinning which are detected using fusion data from the accelerometer, magnetometer, and gyroscope sensors on the phone. The game client on the smartphone starts recording sensor data when a player interacts with a virtual game character through voice-based input by speaking into the phone microphone, thereby indicating readiness to initiate physical action like a jump or a spin. The sensor data are collected for 8 s and processed. In the case of jumps, a peak detection algorithm is employed to find and count the number of jumps. For counting spins, data from all three sensors are collected and the azimuth is calculated. An algorithm is then used to count the number of spins based on a 360° change in azimuth from its starting value. Each quest requires completion of a physical action in order to progress the story.

3.2.3 Tangible feedback

Most mobile phone games use the device screen as both the input and the output interface requiring the player to pay full attention to the screen at all times. Spellbound uses custom-designed hardware to provide a screen-less output interface (see Figs. 1, 2). The wristband, worn by each player, has an array of three LEDs and a small vibration motor where each LED is mapped to one quest. Each time a team completes a quest, the wristbands worn by all members of the opposing team vibrate and one LED each turns on. This way all players have the same game state information. The Aliens team wears wristbands with blue LEDs informing them of the quest progress of the Humans team and vice versa.

The armband is composed of a servo motor and a wire that connects the motor arm to a badge clip. The motor is mounted on a Velcro band and worn on the upper arm by each player. The clip is snapped onto the players' shirt such that each time the motor arm moves, the shirt gets tugged. Each player wears two such armbands. While attempting to locate a hidden virtual item, the player is assisted in their search by the armbands which direct them to take a left or right turn with a tug in addition to the audio output they

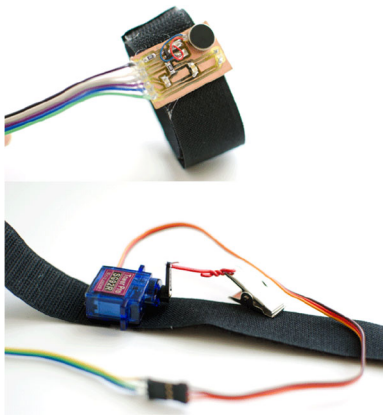

Fig. 1 *Top* wristband with three LEDs and a vibration motor. *Bottom*: armband with a servo motor and a clip

Fig. 2 Player wearing one wristband and two armbands

receive from the phone to guide them in their search. This is a playful mechanic similar to a child trying to catch their parent's attention by tugging on their shirtsleeve. To determine which sleeve should be tugged, we calculate the difference between the bearing of the player and that of the virtual Power Core. Based on the quadrant in which the resulting angle falls, the left or the right sleeve servo is powered on.

4 Actual gameplay

4.1 Starting the game

Players arrive at a predetermined location, and one person starts the game on their mobile device that others then join using their mobile devices. Players are automatically put into two teams with a maximum of three players per team. When the game begins, each team is presented with three quests that they need to complete to win. Each quest is different with respect to the physical interaction needed (jumping, spinning, running), technologies used (armbands, wristbands), involvement of bystanders or passers-by, and cooperative strategies required.

4.2 *Find* quest

The *Find* quest requires players to locate a virtual item (Power Core) hidden in the play area and generate a tornado to dislodge it from its hiding spot. For this quest, players use their smartphone as a "sonar device." They speak into the microphone, and the device responds aloud with "getting warmer/colder" based on their relative position and distance to the location of the hidden Power Core (see Fig. 3). In addition to the audio feedback, a motorized armband tugs on a player's right or left sleeve to point them in the direction of the Power Core. The player continues this process until the item is found. Once the item becomes visible on the map, when players get within a specified

Fig. 3 Player starting the *Find* quest using voice input on their device

Fig. 4 Two players spinning together to complete the *Find* quest

range, they are asked to spin three times. Figure 4 shows two players on the Aliens team spinning together. When at least three spins are detected simultaneously from two team members, the quest is considered complete and the players move on to the next quest. Players are free to strategize their search for the Power Core by splitting up to cover larger ground and coming together at the found location for completing the quest by spinning together.

4.3 *Save* quest

The *Save* quest requires players to stomp out a bug infestation at a specific location in the play area. This spot is marked on the map after the players receive the quest from an NPC (non-player character). Once the bug infestation location becomes visible on the map, when players get within a specified range, they are asked to jump three times (Fig. 5). The movement is detected using sensor data from the accelerometer on the phone. When at least three jumps are detected from two team members (see Fig. 5), the quest is considered complete and the players move on to the next

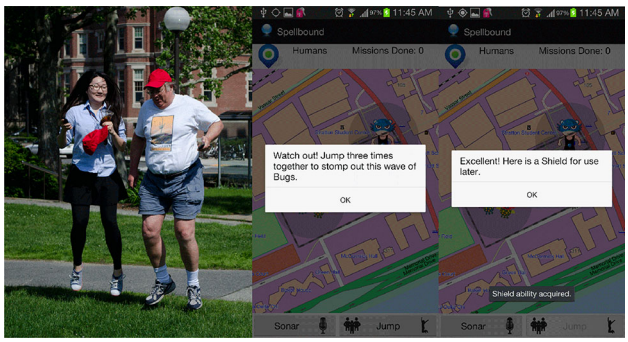

Fig. 5 Two players jumping together on virtual bugs together in the *Save* quest

Fig. 6 Player talking to a passer-by in the *Recruit* quest

quest. It is acceptable for players to jump more than three times or take giant leaps or even tiny hops. The players may cheat and shake their phone instead of jumping to complete this quest. We did not program rules that would disallow such cheating because our paper prototype playtesting revealed that most players will usually play by the rules and keep each other in check. Additionally, doing the physical actions together was found be to the most enjoyable aspect of play during our playtesting.

4.4 *Recruit* quest

The *Recruit* quest requires players to invite participation from any bystanders or passers-by in the play area (see Fig. 6). This quest presents an uncomfortable scenario introducing the idea of shared discomfort as a "powerful social experience" [5] by asking players to interact with a passer-by. The goal is to get the person to speak "I am a smelly bug!" into the phone's speech recognition system. When the game hears that phrase, an NPC responds audibly with "stinky human detected." The players may choose to speak into the phone instead of interacting with a bystander improvising and appropriating the game to their own purposes. The virtual game state is synchronized across all six phones every few seconds, so player location data are up to date and completed quests are no longer available for others to receive. Players on the same team have a few different ways to gauge their team's progress: (1) doing quests together, (2) watching their team members do the movements from afar, and (3) glancing at the phone screen to see which NPCs are still visible and available for interaction.

4.5 Ending the game

The game ends when either team finishes their three quests or when a time limit of 10 min (chosen based on paper prototype playtesting) has been reached. Since the game involves physical movements other than walking, playtesters stated 10 min of playtime was fun without being exhausting. They also reported they got a good workout with the jumping, spinning and running and they would prefer the game be playable in short chapters with a continuing story that tied them together.

5 Evaluation

5.1 Evaluation methodology

In order to evaluate Spellbound, we conducted an experimental user study over three days, with multiple gameplay sessions per day. Participants were recruited by sending e-mails to our department mailing lists and via word of mouth. The goal of the study was to find out from real users their experience of the screen-less physical play, social interaction, and the level of enjoyment in playing Spellbound. Our study involved six playtest sessions with 18 subjects in total between the age of 22 and 45, of which eight were female and 10 were male. The game was played on our campus in a rectangular space of about 100 by 180 m with one building in the center, a few parked vehicles nearby, lots of large trees, and two open grassy areas. The participants were graduate students, staff, and faculty, mostly from our department. Each player was equipped with a GPS-enabled Android smartphone, earphones with built-in microphone, a wristband, and two armbands.

The participants were first introduced to the game rules with a short walkthrough. This was followed by a 10-min trial where the participants played the game. After this first trial, the participants switched teams and played again for another 10 min. At the end of each play session, participants filled out a questionnaire and provided comments on their experience and the game system. We used responses to the questionnaire for quantitative analysis and observation data from play sessions along with interviews

we conducted with the players after each trial for qualitative analysis.

6 Evaluation results

In this section, we present the responses to the questionnaire, verbal comments from players, and our observations made during the play sessions.

6.1 Player survey results

At the end of each play session, participants were asked to fill out an online questionnaire. The questions ranged from opinions about the overall satisfaction/fun they had to questions about how useful were the custom hardware devices and whether they contributed to increased social interaction. From the results, the following basic points are evident:

- All players were positive about the fun factor of the game; 16 % were neutral or lower and 84 % were positive about the appeal of the game to them.
- The majority of players were positive about the social physical actions involved in the game (94 % positive or strongly positive), with the vast majority (17 out of 18) also stating that the use of full-body gestures of jumping and spinning, especially doing them together with their teammates, is more fun than tapping on a touch screen.
- The response was positive about screen-less and hands-free interaction with 83 % strongly positive, while 17 % were neutral or lower probably due to GPS or other sensor error leading to some confusion.
- 77 % found interacting with their devices using voice intuitive and exciting, while the rest felt self-conscious speaking to their devices.
- Players said that additions in the hardware interface, such as orientation data, would be welcome as it would lead to more accuracy in directional guidance by the armbands.
- The overall operation of the system was perceived by the players as satisfactory and almost everyone wanted to play again.

The questionnaire results are also summarized in Figs. 7, 8, and 9.

6.2 Design and interaction evaluation results

6.2.1 Whole-body gestures

All players agreed that physical jumping and spinning gestures for interacting with the virtual world were enjoyable. One wrote: "it is a great way to encourage people to be physically active" and all (but one) said they would like to play it with their friends and family. Players who felt lost due to either technical issues or joining the game late were able to catch up after starting with the group jumping and spinning part of the quest. They reported that being part of a team meant the responsibilities were evenly divided and they had a specific role to play, which made them feel more involved with the game and their teammates. Some players said doing the actions alone outdoors would make them feel self-conscious but doing them with their team made them feel like they were "part of a secret club that others had no idea about" and that made playing more fun. One player said "doing silly actions with others is fun" while another found the team aspect "a great way to encourage people to be physically active." Players were laughing and high-fiving after each action following which they discussed their strategy for the next quest and then acted on it. We noticed two players go from being visibly stressed to being relaxed and full of laughter after spinning around in circles with their teammates. They later told us how thankful they were for having decided to participate in our playtesting. During play, we heard "Let's do this quest first, it's easier," "Let's split up and spread out to find the Power Core," "Hurry! The other team already finished one quest," some of the many strategies that evolved as player's made progress or received information about the other team's progress through their wristbands. A number of participants commented that they liked the idea of "social approach to physical activity" and "story based activity" which made them "feel like a kid" and made "familiar surroundings more exciting."

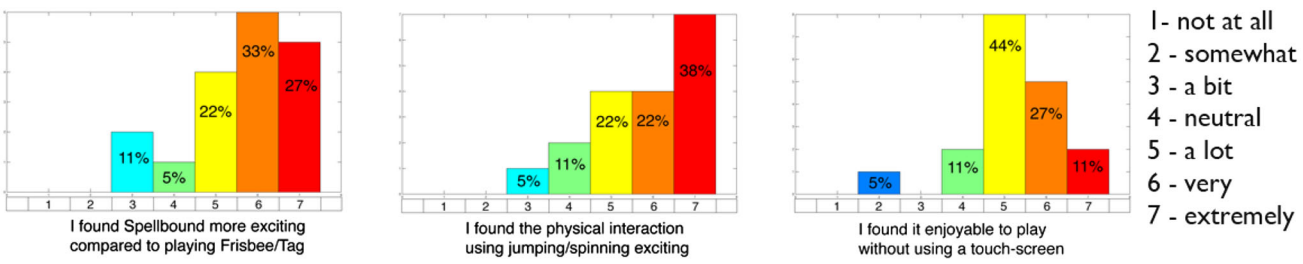

Fig. 7 Answers from players regarding enjoyment during play

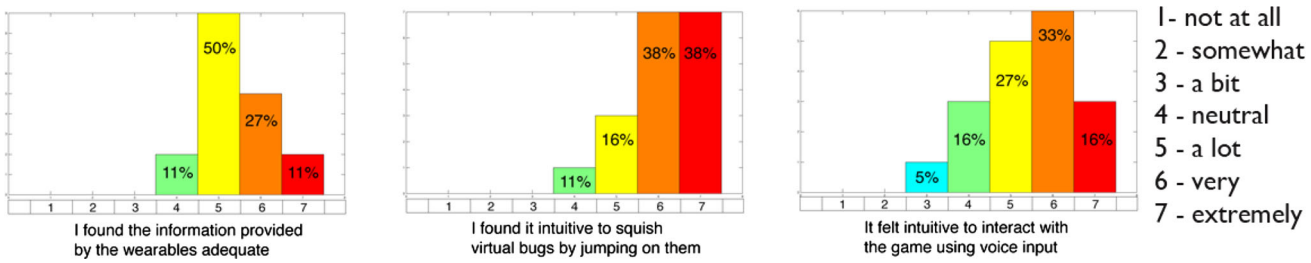

Fig. 8 Answers from players regarding input methods

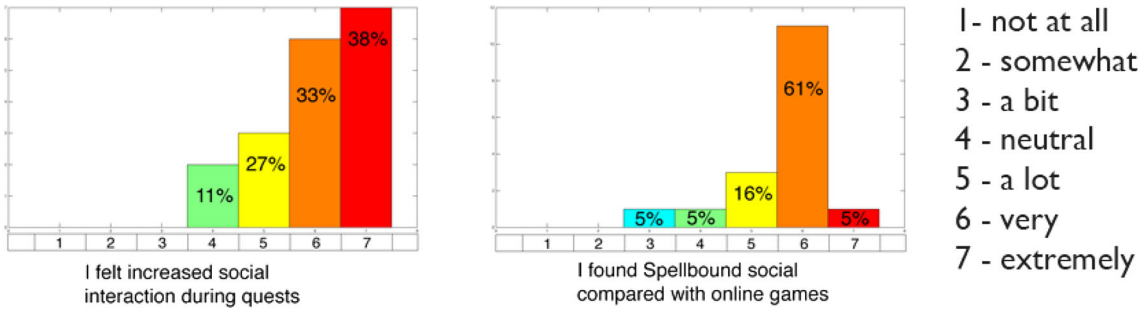

Fig. 9 Answers from players regarding level of social engagement

6.2.2 Haptic feedback

Regarding the armbands' efficacy for guiding players to locate the hidden virtual item, several players found the tug was not strong enough to mimic a sleeve tug. One player, however, said they came to rely upon it to guide them in their search, but they would have preferred "shorter faster tugs." All players enjoyed wearing the hardware, and some remarked that it made them "look cool" and feel like they were "special." The wristband affected player behavior dramatically. One player said they increased their speed and effort to locate the Power Core when they saw the first LED turn on, but switched to a different quest entirely when the second LED came on, saying "after the second light, I was full on panic mode." They said they constantly glanced at the wristband to make sure they did not miss any information. All players remarked how quickly they could access information saying there was no thought between the wristband vibrating and them looking at it. A player ran up to their teammates to confirm what they felt, saw, and interpreted from the wristband and said they imagined the other team coordinating their quests differently from their own play strategy. Similarly, when a team finished their quest, they said they felt a connection with the other team through the wristband and reported it as "telepathic communication," wordless yet palpable. The ability to make eye contact with others instead of staring at a screen was appreciated by everyone. Most players felt the wrist was the perfect placement for a wearable that provides game state information. We used LEDs on the wristband to provide a secondary glanceable source of information that was temporally static and thus available for viewing after the motor stopped vibrating. Everyone agreed it was easier and faster to glance at their wristband than trying to get the same information from the device. Between the wristband and being able to look around and observe the other team in the play space, players reported they had enough information to plan their next course of action in the game.

6.2.3 Voice input and audio output

One player found the voice interaction with their device particularly exciting and wrote: "it made me feel like I was a secret agent in some organization" but found the narrative too short and simplistic. All players agreed the game was too short and would have been even more fun if there were several more quests and if the game was played over a larger area. All players were comfortable interacting with their device using voice input and enjoyed the audio responses from the game characters. One player said they wanted more dramatic sounds and more dialog to add to the fun. Seventy-seven percentage found it intuitive to interact with the device using voice instead of touch and preferred it, especially for an outdoor game. The rest felt self-conscious with the choice of keyword *hootie* used for interacting with the game during the *Find* quest as it was audible to passers-by in the play space (the word was chosen because of its distinctiveness and ease of

recognition by the speech recognition system even for non-native English speakers). One player continued to say *hootie* every time we crossed paths for weeks after the playtesting was done. All players found the audio output (sound effects, virtual character speech) useful and even necessary to help them stay engaged with events in the real world while easily tracking those in the virtual world. They appreciated that information was available through multiple channels (haptic, audio, visual) and they could choose how to receive it.

6.2.4 Communication

In a fast-paced game like Spellbound, played in a relatively small outdoor space (size of a football field), players reported talking to team members was faster and more efficient than texting would have been. One player expressed the desire for "push-to-talk" to communicate with their team members, while all others enjoyed the running over to their teammates or yelling for their teammates to come over for sharing quest progress and discovery. Collaboration, inclusion, and strategy were elements of play made visible not only because of quest design but also due to communication. After the game ended, players narrated their *Recruit quest* experience to everyone and felt a sense of pride almost at having successfully made a stranger verbally admit to being a stinky bug/human. This was the most awkward quest but also one where players could have easily cheated as there was nothing in the system that was checking whether they spoke with a passer-by or not. In all our playtest sessions, nobody cheated, but one player asked what would have happened if they had.

The game communicates using spoken dialog to make the player aware of their proximity to a non-player character (NPC) or other virtual element of the game. The dialogs are spoken in different voices and are different for both teams, both in content and style, but are limited to short phrases. In outdoor spaces with high ambient noise, there is always a possibility for the player to not hear the spoken dialog or remember what was spoken so the system needs to be designed such that repetition is possible on demand. In Spellbound, players can access all information through the device screen if needed.

An important outcome of playing without constantly glancing at the phone screen is that players can often become so involved in the game experience that they fail to take into account obstacles present in the real world. We avoided this by designing for reduced interaction with the device screen as well as using an outdoor public space (park, field, campus) instead of city streets as our play space.

7 Discussion

As learned from the findings, most users are excited about Spellbound. Their enthusiasm was mildly impacted by technical issues such as GPS update lag, especially when the player was close to buildings, or activity detection issues which occurred for four out of 18 participants during spinning. When compared with the traditional playground game of *Tag*, 17 % of the users entered a neutral or lower stand in their preference, while 83 % ranked it more entertaining, indicating that Spellbound is preferred over Tag in terms of entertainment value ($p < 0.05$). Based on the evaluation results, we have identified two salient themes that contributed to the goal of enhancing social interactions in our team-based game.

7.1 Sensory gameplay

Because the game was played in a relatively small outdoor space and no digital communication option was designed, players would visually scan the entire area and keep their ears open, engaging with the world as they normally would. Hearing their teammates call or interactions between players of the other team would allow them to understand and learn the flow of the game in ways not easily possible through data on a screen. For example, by hearing the other team, a player would be able to determine which quest was currently being undertaken and whether they were close to completing it or not. Seeing your own team scattered over the play area could help gauge how much time would it take them to come together at a quest location and how could you best optimize communication in that situation. All these real-world data take our brains less than a few seconds to process, but it results in a kind of nuanced interaction between players and the game that digital communication rarely affords, leading to continually evolving gameplay over time. All players said they were comfortable wearing the designed hardware as it was light and answers to question regarding playing a mobile game without using touch-based input show 83 % of the players found the screen-less hands-free interaction more enjoyable ($p < 0.05$). We believe, because players do not have to continually look at their devices for playing the game, they were better able to focus on their teammates and the world around them, which led to increased face-to-face communication, eye contact, and overall increased social interaction with a reported greater sense of belonging and participation. Additionally, feeling the wristband vibrate added a visceral sense of urgency to gameplay which was evident in changes in running patterns, sounds, and general excitement in the play area. We expected some players to shake their devices instead of jumping, but we

did not see that. This was likely due to the actions being the most socially enjoyable part of the game but could also be because players were in a playtest session and therefore wanted to follow all rules. Our hardware can be replaced by recently introduced smart watches which can be programmed to accomplish similar output and would make the game playable by anyone who owns these devices.

7.2 Concurrent actions

Playground games like *Tag* involve a high degree of physical participation which indicates that the element of physical interaction with the virtual world was not the sole attraction in Spellbound. Findings about enthusiasm and about excitement level during physical actions of jumping and spinning (94 % found it exciting, one player was not enthused, $p < 0.05$) show that the social element of doing the full-body gestures together likely contributed to greater enjoyment. Players felt less socially awkward doing the actions together and laughed with joy while doing them. We believe the alternative of texting "lol" to teammates or sending emoticons may not have led to the same kind of bonding as elicited by laughter over a shared collocated activity. Many cultural anthropologists believe that laughter occurs when people are comfortable with one another, when they feel open and free, which leads to strengthening the bond between them [7]. We saw this happen over the course of the two game sessions for each team as players became more familiar with the rules of the game and also learned a little bit about their teammates. The physical actions invited participation and made it easy for everyone in the team to contribute to making progress in the game. Those that felt left out used it as an opportunity to jump back into the game. The actions also served as a checkpoint in the game giving players a chance to mentally pause and collect their thoughts and plan ahead. We had expected the slight dizziness from spinning to be accompanied by childlike glee but that was not the case for most players. We believe this design element of having people perform gestures together expanded the play and learning space beyond the personal device screen [31], thereby contributing to enhanced togetherness.

8 Findings

Limited user playtesting validates our game design goal of increasing social interaction which, in our case, resulted in making physical activity more appealing. We present this connection a bit loosely because our design and evaluation focused on increasing social connection with an assumption that engaging social interaction can make things like physical activity desirable. Because our observation data and player comments attest to that outcome we feel, it is appropriate to at least mention it here. Overall, our evaluation largely verifies the research contributions in the design of Spellbound that helped achieve the goal of increased social engagement. The main conclusions are summarized as follows:

- Designing games that take into account player interactions in the real world can increase social interaction and enjoyment.
- The ability to receive information through a non-visual channel (haptics) may be a useful instrument for maintaining flow of the game by reducing continual context switching between the real world and the screen. Additionally, utilizing voice as a more natural way of input may increase player engagement and game appeal.
- The short fast-paced nature of the game will be appreciated by players who want a burst of enjoyable social and physical activity without requiring scheduling, planning, and commitment for a larger event, for example, when having a break from work/school.
- The game is spatially confined to a predetermined location which is a limitation that can be overcome by creating a Web interface for defining new game spaces. Currently, our interface is clunky and only for our use as developers.
- The size of the play space determines modes of communication employed and their impact on social engagement. Smaller spaces lend themselves to increased face-to-face interactions than similar games played over larger spaces.
- Matching the full-body gestures to relevant actions and outcomes in the virtual game, for example, jumping in the real world, matches squishing virtual bugs in the game world.
- Sensor malfunction is inevitable and can lead to player frustration. The game design needs to account for this possibility, especially since not everyone will do an action in the same exact manner.

We see some technical issues that are likely to plague similar games, such as latency in communication of game state to all players, which depends on the type of data connectivity available in the play area, and extremely large GPS inaccuracies especially near large buildings can cause the game to derail for affected players. For example, there were a few engineering challenges that we needed to overcome: limitations of our Android 2.4 test devices with no data plan, networking, and latency issues for real-time multiplayer gameplay, reliable physical action detection, and communication with the custom hardware devices, to make for mostly smooth gameplay during the evaluation. Here we list a few questions that we believe are interesting

and follow from our findings. How can we access more contextual information for making such experiences feel more immersive while simultaneously pushing technology into the background? What other output mechanisms can we successfully use outdoors that will reduce the need for looking at phone screens? How would social play experiences feel if they were designed for smart watches or HMDs?

9 Conclusion

In this article, we described the game concept, design process, and the technical realization of a team-based pervasive game called Spellbound. We introduced Spellbound, an outdoor team-based pervasive game, that uses whole-body gestural input and provides haptic output. We described the theoretical background to the Spellbound experience, for example how the game aims to use physicality and laughter as a form of bonding in order to make richer and more engaging social interactions supported by technologies that "vanish into the background" [50]. The paper also presented the iterative design process and development of the system, including the concepts, devices, and narrative. Furthermore, we presented the rules of stage I of our prototype game to demonstrate and evaluate our design decisions and briefly discussed its implementation.

Through a series of playtesting sessions, we evaluated our implementation and the response of players to our game. Our results indicate a very positive response, especially to the physical and hands-free style of play encouraged and supported by the design of the game. We tested with a maximum of six players per game session due to the limited number of wristbands and armbands we had time to create, but we believe a larger number of players can be supported by our client–server architecture without compromising the gaming experience. Players perceived the game as an interesting social take on physical activity and welcomed the idea of being able to play in physical space where the game turned familiar locations into fantasy realms. Our chosen design elements helped outline the use of actions, tactile senses, space, and communication for a pervasive game that aims to augment social, collocated activities as supported by mobile technologies.

Our future work includes the implementation of the game using smartwatches instead of custom hardware and smartphone devices, refinement of our implementation with a deeper narrative and larger variety of actions (hopping, arm waving), additional sensors (heartrate) for more context, and polishing our Web-based interface for creating, watching replays, and sharing games for user by players.

Acknowledgments We would like to thank Skyler Adams for help with the hardware, all the players for their feedback, as well as Leo Burd and Josh Sheldon at the MIT Center for Mobile Learning for lending us six Android smartphones without which playtesting and evaluating Spellbound would not have been possible.

References

1. Ballagas RA, Kratz SG, Borchers J, Yu E, Walz SP, Fuhr CO, Hovestadt L, Tann M (2007) REXplorer: a mobile, pervasive spell-casting game for tourists. In: CHI'07 extended abstracts on Human factors in computing systems, ACM, pp 1929–1934
2. Bekker T, Sturm J, Eggen B (2010) Designing playful interactions for social interaction and physical play. Pers Ubiquitous Comput 14(5):385–396
3. Bell M, Chalmers M, Barkhuus L, Hall M, Sherwood S, Tennent P, Brown B, Rowland D, Benford S, Capra M, Hampshire A (2006) Interweaving mobile games with everyday life. In: CHI '06, CHI '06, ACM, pp 417–426
4. Benford S, Crabtree A, Flintham M, Drozd A, Anastasi R, Paxton M, Tandavanitj N, Adams M, Row-Farr J (2006) Can you see me now? ACM Trans Comput Hum Interact 13(1):100–133
5. Benford S, Greenhalgh C, Giannachi G, Walker B, Marshall J, Rodden T (2012) Uncomfortable interactions. In: Proceedings of CHI '12, CHI '12, ACM, pp 2005–2014
6. Bianchi-Berthouze N, Kim W, Patel D (2007) Body movement engage you more in digital game play? and why?. In: ACII '07, pp 102–113
7. Brain M (2000) How laughter works. HowStuffWorks. com. http://people.howstuffworks.com/laughter7.htm. Accessed 1 Oct 2006
8. Brewster S, Brown LM (2004) Tactons: structured tactile messages for non-visual information display. In: Proceedings of the fifth conference on Australasian user interface-volume 28, AUIC '04, Australian Computer Society, Inc., pp 15–23
9. Capra M, Radenkovic M, Benford S, Oppermann L, Drozd A, Flintham M (2005) The multimedia challenges raised by pervasive games. In: Proceedings of the 13th annual ACM international conference on multimedia, ACM, pp 89–95
10. Chatzigiannakis I, Mylonas G, Akribopoulos O, Logaras M, Kokkinos P, Spirakis P (2010) The "hot potato" case: challenges in multiplayer pervasive games based on ad hoc mobile sensor networks and the experimental evaluation of a prototype game. arXiv preprint arXiv:1002.1099
11. Cheok AD, Goh KH, Liu W, Farbiz F, Fong SW, Teo SL, Li Y, Yang X (2004) Human Pacman: a mobile, wide-area entertainment system based on physical, social, and ubiquitous computing. Pers Ubiquitous Comput 8(2):71–81
12. Crabtree A, Benford S, Rodden T, Greenhalgh C, Flintham M, Anastasi R, Drozd A, Adams M, Row-Farr J, Tandavanitj N et al. (2004) Orchestrating a mixed reality game'on the ground'. In: Proceedings of the SIGCHI conference on Human factors in computing systems, ACM, pp 391–398
13. Dourish P (2001) Where the action is: the foundations of embodied interaction. MIT Press, cambridge
14. Eichberg H et al (2010) Bodily democracy: towards a philosophy of sport for all. Taylor & Francis, Routledge
15. Eriksson E, Hansen TR, Lykke-Olesen A (2007) Movement-based interaction in camera spaces: a conceptual framework. Pers Ubiquitous Comput 11(8):621–632
16. Garner J, Wood G, Pijnappel S, Murer M, Mueller F (2013) Combining moving bodies with digital elements: design space between players and screens. In: IE '13, ACM, 17:1–17:10

17. Gerling K, Livingston I, Nacke L, Mandryk R (2012) Full-body motion-based game interaction for older adults. In: CHI '12, ACM Press, pp 1873–1882
18. Graves L, Stratton G, Ridgers ND, Cable NT (2008) Energy expenditure in adolescents playing new generation computer games. Br J Sports Med 42(7):592–594
19. Gunther EEL (2001) Skinscape: a tool for composition in the tactile modality. PhD thesis, Massachusetts Institute of Technology
20. Hampton KN, Sessions LF, Her EJ, Rainie L (2009) Social isolation and new technology. Pew Internet Am Life Proj 4:5–22
21. Herbst I, Braun A-K, McCall R, Broll W (2008) TimeWarp: interactive time travel with a mobile mixed reality game. In: Proceedings of the 10th international conference on human computer interaction with mobile devices and services, ACM, pp 235–244
22. Isbister K (2011) Emotion and motion: games as inspiration for shaping the future of interface. Interactions 18(5):24–27
23. Isbister K, Schwekendiek U, Frye J (2011) Wriggle: an exploration of emotional and social effects of movement. In: Extended Abstracts CHI '11, ACM Press, pp 1885–1890
24. Jantke KP, Arnold O, Spundflasch S (2013) Aliens on the bus: a family of pervasive games. In: Consumer electronics (GCCE), 2013 IEEE 2nd global conference on, IEEE, pp 387–391
25. Kasapakis V, Gavalas D (2014) Blending history and fiction in a pervasive game prototype. In: Proceedings of the 13th international conference on mobile and ubiquitous multimedia, MUM '14, ACM
26. Koster R (2004) A theory of fun for game design. Paraglyph Press, Scottsdale
27. Kurczak J, Graham TCN, Joly C, Mandryk RL (2011) Hearing is believing: evaluating ambient audio for location-based games. In: ACE '11, ACM, 32:1–32:8
28. Labs N (2013) Ingress, https://www.ingress.com/
29. Lindley SE, Le Couteur J, Berthouze NL (2008) Stirring up experience through movement in game play: effects on engagement and social behaviour. In: Proceedings of the SIGCHI conference on human factors in computing systems, ACM, pp 511–514
30. Lindt I, Ohlenburg J, Pankoke-Babatz U, Ghellal S (2007) A report on the crossmedia game epidemic menace. Comput Entertain (CIE) 5(1):8
31. Lundgren S, Fischer JE, Reeves S, Torgersson O (2015) Designing mobile experiences for collocated interaction. In: Proceedings of CSCW?15
32. Lyons EJ, Tate DF, Ward DS, Bowling JM, Ribisl KM, Kalyararaman S (2011) Energy expenditure and enjoyment during video game play: differences by game type. Med Sci Sports Exerc 43:1987–1993
33. Magerkurth C, Cheok AD, Mandryk RL, Nilsen T (2005) Pervasive games: bringing computer entertainment back to the real world. Comput Entertain 3(3):4
34. Malone TW (1981) Toward a theory of intrinsically motivating instruction. Cogn Sci 5(4):333–369
35. McGonigal J (2011) Reality is broken: why games make us better and how they can change the world. Penguin group, London
36. Misund G, Holone H, Karlsen J, Tolsby H (2009) Chase and catch - simple as that?: old-fashioned fun of traditional playground games revitalized with location-aware mobile phones. In: ACE '09, ACM, pp 73–80
37. Moran S, Pantidi N, Bachour K, Fischer JE, Flintham M, Rodden T, Evans S, Johnson S (2013) Team reactions to voiced agent instructions in a pervasive game. In: Proceedings of the 2013 international conference on intelligent user interfaces, ACM, pp 371–382
38. Mueller F, Edge D, Vetere F, Gibbs MR, Agamanolis S, Bongers B, Sheridan JG (2011) Designing sports: a framework for exertion games. In: Proceedings of CHI '11, ACM Press, pp 2651–2660
39. Mueller F, Gibbs MR, Vetere F (2009) Design influence on social play in distributed exertion games. In: Proceedings of the SIGCHI conference on human factors in computing systems, ACM, pp 1539–1548
40. Mueller F, Isbister K (2014) Movement-based game guidelines. In: CHI '14, ACM Press
41. Salem K, Zimmerman E (2004) Rules of play. MIT Press, Cambridge
42. Stine E (2011) Location-based games: from screen to street. PhD thesis, The Danish School of Education, Aarhus University, Center for Playware
43. Strömberg H, Väätänen A, Räty V-P (2002) A group game played in interactive virtual space: design and evaluation. In: Proceedings of the 4th conference on Designing interactive systems: processes, practices, methods, and techniques, ACM, pp 56–63
44. Sutton-Smith B (2009) The ambiguity of play. Harvard University Press, Cambridge
45. Tan HZ, Pentland A (2005) Tactual displays for sensory substitution and wearable computers. In: ACM SIGGRAPH 2005 Courses, ACM, p 105
46. Thomas B, Close B, Donoghue J, Squires J, Bondi PD, Piekarski W (2002) First person indoor/outdoor augmented reality application: Arquake. Pers Ubiquitous Comput 6(1):75–86
47. Six to Start (2013) Zombies, run!. https://www.zombiesrungame.com/
48. Van Erp JB (2002) Guidelines for the use of vibro-tactile displays in human computer interaction. In: Proceedings of eurohaptics vol 2002, pp 18–22
49. Wakkary R, Hatala M, Jiang Y, Droumeva M, Hosseini M (2008) Making sense of group interaction in an ambient intelligent environment for physical play. In: Proceedings of the 2nd international conference on Tangible and embedded interaction, ACM, pp 179–186
50. Weiser M (1991) The computer for the 21st century. Sci Am 265(3):94–104