Exertion Games

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Contents

Abstract

Advances in human-computer interaction (HCI) technologies have led to emerging computer game systems that foster physical exertion as part of the interaction; we call them exertion games. These games highlight a body-centric perspective on our interactions with computers, in contrast to traditional mouse, keyboard and gamepad interactions, not just in terms of their physical interface, but also in terms of the experiences that they support. As a result, exertion games show great promise in facilitating not only health benefits, but also novel play experiences. However, to realize this promise, exertion games need to be well designed, not only in terms of technical aspects involving the sensing of the active body, but also in relation to the experiential perspective of an active human body. This article provides an overview of existing work on exertion games, outlines a spectrum of exertion games, and presents an analysis of key enabling technologies. We also position exertion games within a broader HCI context by reviewing and examining different design approaches and frameworks for building exertion games. Finally, the article concludes with directions for future work.

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1
Introduction

Advances in human–computer interaction (HCI) technologies have led to emerging computer systems that place the users' bodily actions at the center of the experience, fostering physical exertion as part of the interaction. These "exertion" interactions are interactions with technology that require physical effort from the user [Mueller et al., 2003], in contrast to the hitherto prevalent interactions with computers that require only minimal physical effort, such as mouse and keyboard or gamepad interactions. There has been an ongoing trend in recent years that highlights that there can also be benefits if the interaction requires physical effort, supported by a phenomenology-driven philosophical shift in HCI that acknowledges the role of the human body when interacting with computers [Dourish, 2001]. We find that this "turn to the body" is exemplified most notably around digital entertainment, where physical effort facilitates engaging play experiences. In particular, computer games probably provide the most buoyant genre for exertion-based systems so far.

Dance Dance Revolution [Behrenshausen, 2007] is probably the first exertion game that saw considerable commercial success. It is an arcade game that requires players to follow dance instructions on a screen based on music beats by stepping on touch-sensitive tiles on the floor, resulting in exerting dance moves. Following this, Nintendo allowed for exertion actions across a whole range of console games with the Wii [Nintendo]: it uses handheld pointing devices that can detect large arm movements as input for computer game interactions. Sony's Playstation Move [Sony, 2010] arrived as an answer to the Wii to detect the position of its motion-sensing controllers that users wave around in order to interact with the game. Microsoft's Kinect and its successor Kinect 2 [Microsoft, 2010] also aim to support exertion interactions by using a depth-sensing camera to track players' bodily actions. Exertion systems beyond the console and arcade game market exist, too. For example, the Nike + app uses a mix of wearable sensors (originally a sensor in the shoe, then GPS and accelerometer data) to track a user's jogging performance [Apple, 2016]. The jogger can upload the data and engage in social exchange and competitive challenges with a worldwide community of Nike + joggers online. Many similar jogging apps now exist on all major mobile phone platforms. Computationally-augmented bikes [Tacx, 2009] allow for investing physical effort on stationary systems that are connected to the internet. The rider's performance is distributed amongst participants who engage in competitive races with their avatars on virtual cycling tracks.

We see both the more game-focused systems and the more exercise-focused systems represent forms of exertion game systems, as they are comprised of interactive technology, physical exertion, and a play or game element. Together, the aforementioned examples suggest that physical exertion is becoming a prominent component of the many ways in which we interact with interactive technology, and games appear to lend themselves to these types of interactions. In response, this article assembles prior work in this area in order to articulate fundamental issues, implementation and theoretical approaches as well as present opportunities and challenges for the field. Of course other authors have examined the field previously [for examples, see Altamimi and Skinner, 2012, Biddiss and Irwin, 2010, DeSmet et al., 2014, Gekker, 2012, Mark et al., 2008, Papastergiou, 2009, Peng et al., 2012], however, they have mostly focused on specific aspects, such as health objectives [DeSmet et al., 2014, Mark et al., 2008, Papastergiou, 2009], promoting physical activity in children [Altamimi and Skinner, 2012, Biddiss and Irwin, 2010], quantitative approaches [Peng et al., 2012] or EU trends [Gekker, 2012], whereas our approach aims to present a comprehensive HCI perspective on exertion games.

The remainder of this article is organized as follows. In Section 2, we review alternate definitions and classification approaches towards understanding exertion games. In Section 3 we describe existing examples of exertion games mapped across three categories: Digital games, in-between games, and augmented sports. Next, in Section 4, we describe conceptual understandings used to develop exertion games that include theoretical frameworks and design cards as well as strategies. In Section 5, we supply information on various technologies that are used to create exertion games. We conclude by mapping out the future for exertion games. In the next section, we begin the investigation by defining exertion games.

2

Definition of Exertion Games

Altogether, the aforementioned systems contribute to a design space that highlights the role of physical exertion when interacting with technology in a game context. Consequently, we define *an exertion game as a digital game that utilizes physical exertion interactions where the physical effort is a key, if not the dominant, determinant in reaching the game's goal.* This physical effort results in exertion as a consequence of bodily movement produced by skeletal muscles during gameplay that results in energy expenditure. We focus on gross-motor movement to differentiate from the previously predominant fine-motor movement of gamepad, mouse and keyboard operation.

Various researchers have given alternative definitions or used alternative terms, such as exergame, for exertion games. We now examine the most important ones to illustrate the range of the field.

2.1 Alternative definitions

Wikipedia explains that exergaming is a portmanteau for "exercise" and "gaming" in order to describe video games that are also a form of exercise, quoting Sinclair et al. [2007] who said that exergaming is the "use of video games in an exercise activity". We prefer the term exertion over exercise (due to the common connotation that exercise entails a desire for "health improvement" [Gale Encyclopedia of Medicine, 2008] and therefore a colloquial association that it cannot be "much fun"). Furthermore, we highlight that our definition mentions digital games, meaning not just video or screen-based games; that is, for us, an exertion game can also be an audio-only game [Mueller et al., 2010b]. Also, we stress that our definition includes that the exertion is a key component in reaching the game's goal, whereas according to Sinclair et al.'s [2007] definition the use of playing button-press videogames while running on a treadmill is also exergaming.

Adams et al. propose the following definition: "video games that use exertion-based interfaces to promote physical activity, fitness and gross motor skill development" [2009]. This definition raises the question of whether the game is still an exertion game if it requires — but fails to promote — physical activity, fitness and gross motor skill development. Similarly, [Oh and Yang, 2010] come from a health-promotion agenda when they summarize definitions and conclude: "Exergaming is playing exergames or any other video games to promote physical activity". The authors comment on common problems when trying to define these games. They highlight the lack of clear terminology as a main issue. The authors suggest a new definition: Games that foster "players' physical movements that is generally more than sedentary and includes strength, balance, and flexibility activities" [Oh and Yang, 2010].

Bogost defines exertion games as "games that combine play and exercise", "that use physical input devices" [2005] when talking about the Wii, possibly not considering camera-based input devices such as the Kinect.

The term active video gaming is also used (in particular by health researchers such as [Taylor et al., 2012, p. 1260; Peng et al., 2012, p. 1262]) and often defined as describing "video games that provide physical activity or exercise through interactive play" [Mears and Hansen, 2009]. Very similar to our definition is Lieberman's [2006]: they discuss games that "have an interface that requires physical exertion to play the game." An interesting point with this (and hence our

Table 2.1: Our definition's key elements.

Key definition element	Digital game	Requiring physical exertion	Affecting game outcome	Health objective
Our definition	X	X	X	—

definition) is whether an exertion game is still an exertion game if players find out alternative ways to play the game; consider, for example, Nintendo Wii Tennis: players quickly learned that thanks to the limitations of the sensing technology, they can also play successfully by just flicking their wrists instead of using whole-arm tennis swings. As such, a question to raise is whether the intention of the designer is important (that is, did the game designer intend that physical effort would affect the game's goal?) or how the player appropriates the game (that is, is a player who decides to put a gamepad controller on the ground and operate it while using push-ups turning a non-exertion game into an exertion game?).

In this context, Silva and El Saddik [2011] argue that the focus on either gameplay or exertion should be considered when categorizing games (2011); with exertion games mainly focusing on game elements and providing a playful experience, and game-based exercising having a much stronger emphasis on exertive elements.

In conclusion, despite nuanced views regarding the balance between exertion and gameplay, all approaches aiming to describe the integration of physical activity into games highlight the importance of physical effort as a core criterion for a game to be classified as an exertion game; hence, requiring physical effort of players to affect the outcome of the game is for us a defining feature. We summarize the key elements of our definition in Table 2.1, contrasting it with other prominent definitions.

2.2 Other related approaches for classifying exertion games

Besides alternate definitions of exertion games, a range of theoretical frameworks also exist in the literature that help us in classifying exertion games from a more comprehensive perspective on the elements they integrate and the experience they provide. For example, a framework proposed by Mueller et al. [2009a,b] takes into account aspects that extend beyond exertion, exploring the impact of social elements of play and the importance of player engagement, suggesting that all of these aspects contribute to meaningful play that provides a valuable player experience. In contrast, Yim and Graham [2007] focus on elements of exertion interface design and their implications for player experience, and argue that aspects such as the locality and mode of play (for example, mixed reality gaming) need to be considered to accurately map the exertion gaming landscape.

A high-level classification of exertion games has been provided Mueller et al. [2008]. After a primary distinction between non-exertion games and exertion games, the authors differentiate between non-competitive and competitive exertion games, which allow players to engage in competition with each other and compare their performances. They then distinguish further between non-parallel and parallel competitive exertion games depending on the interaction patterns that are provided.

Other relevant frameworks had previously emerged in the interaction design field through considering how moving bodies interact with technology, which is a building block of an understanding of exertion games often investigated under the topic of movement-based interactions — for examples, see England et al. [2009], Fogtmann et al. [2008], Larssen et al. [2004], Loke et al. [2007], Moen [2006].

Eriksson et al. [2007] presented a framework that serves as lens to describe the various positions of the body and its limbs when users are moving around interactive installations, which can include games. This work focuses on camera-based interactions and therefore applications where users occupy a pre-defined space; as such, it provides an understanding of the different ways in which technology can handle users moving around a physical space.

Hornecker and Buur [2006] presented a tangible interaction framework that considers the body in relation to social spaces filled with tangible objects. The various ways of considering the interactions between an exerting body and tangible objects is particularly relevant when considering the many objects that are used in traditional sports; for example, Jensen et al. have used traditional footballs on an augmented sports pitch to create novel exertion games around training football skills [Jensen et al., 2015].

Loke and Robertson [2013] developed a methodology to support working with the moving body and the kinaesthetic sense, originating from dance and movement improvisation. The authors' focus is on the relationship between the computer, the moving user and the audience, extending our understanding by a heightened consideration of the "felt" experience when one is exerting.

Moen [2006] advocated considering the pleasure that arises when users are exerting in her argument for a kinaesthetic movement interaction perspective, also originating from dance. She derives her understanding of movement in interaction design primarily from a single user–single device perspective, in response, several works have considered multiple players and multiple devices since then. For example, Segura et al. [2013] presented a design space for "body games," which appears to equally apply to exertion games. Their work highlights the technological, physical, and social issues that arise during the design process. The authors stress that by shifting the focus from movement as interaction technique to the social experience of the players in the game, the social and physical settings become important design resources.

Hummels et al. [2007] have drawn on their design expertise to develop a structured approach towards designing for what they call moving bodies. They conceptualize bodily movement as a design material and give practical advice how designers can develop bodily movement skills.

Ludvigsen et al. noted in their design work with handball athletes that it is important for designers to consider the entire range of possibilities of how bodies interact with one another, including intense body contact that can occur during play [Ludvigsen et al., 2010], something that many interactive systems seem to shy away from due to often fragile technology [Mueller et al., 2014b].

Fogtmann from the same research group coined the term "kinesthetic empathy" in order to describe how bodily actions are affected by other people during sports activities, for example, when players bump into and push each other: they describe it as the other person's body is affected not only by their own muscle actions, but also by someone else's [Fogtmann, 2007, Fogtmann et al., 2008]. The authors point out that not all activities are so easy to categorize as handball, and that there are different levels of kinesthetic empathy.

Voida et al. [2010] studied how people engage with commercial exertion games. Two major findings from this study were: (1) the design of the game can significantly influence how players relate to one another; and (2) the consideration of both the virtual and the physical space is important to understand players' experiences. In particular, they articulate how design features in the virtual space, such as special effects and promoting competitive behavior, can shape how players are interacting with one another in the physical space.

Bekker et al. [2010] used a research through design approach to derive three design values for designing playful interactions for social interaction and physical play, for us a precursor for exertion games. These three design values are: Interactive play objects can stimulate social interaction and physical play by providing feedback to players' behavior; they can allow players to create their own game goals and rules in an open-ended play context; and (3) they can support social player interaction patterns.

When it comes to research specific to social exertion games, de Kort and IJsselsteijn [2008] argue that social play can be categorized according to whether participants are acting or observing, competing, co-operating, or co-acting.

In summary, classification approaches can assist in the analysis of exertion games as well as in the creation of novel exertion games. In the following section, we describe some of the key examples of such exertion games.

3

Spectrum of Exertion Games

We now present typical examples of exertion games in order to derive a spectrum of exertion games (Figure 3.1). In line with our definition's focus, our organization is based on the physical activity necessary to engage with the game while also considering the degree of gameplay. As such, we hope our approach is able to complement existing approaches to provide an overview of the field, for examples of other approaches see categorizations to inform future funding [Mears and Hansen, 2009] or taxonomies based on historical accounts [Bogost, 2007, Chapter 10; Johnson, 2008; Lazarus, 2010; Orland and Remo, 2008; Sinclair et al., 2007].

Our spectrum builds on previous work by Gerling and Mandryk [2014] that distinguishes between different types of exertion games based on their emphasis on physical activity as a driving component of the experience, or a gameplay-based approach. Unlike prior approaches that distinguish sharply between different types of exertion games (such as Mears and Hansen [2009]), we see our examples sitting across a spectrum: on the one end of the spectrum, there are digital games that incorporate exertion, on the other end there are sports activities that

Figure 3.1: Exertion games lie on a spectrum that has an either digital or sports component.

incorporate digital play, and then there are examples that sit somewhere in between. Our aim is to highlight a range of examples across the spectrum in order to demonstrate the breadth of the field. As such, we have included examples we believe exemplify and stand for a certain class of exertion games that made a significant contribution to the field. Consequently, we do not provide a complete list of games nor is our approach unbiased; on the contrary our approach represents a personal perspective on the field.

We start by describing digital games that incorporate exertion. We present both commercial and academic examples.

3.1 Digital games that incorporate exertion

Digital games that incorporate exertion are digital games that typically come from a digital game background and involve a low degree of physical activity but feature rich gameplay.

3.1.1 Commercial examples

A very popular example of commercial games is Nintendo's Wii [Nintendo], which features the Wii Remote controller that uses accelerometer information. The well-known Wii Sports game [Nintendo] that runs on the platform consists of four different mini games. In Bowling, the player holds the Wii Remote in his or her hand similar to holding a bowling ball. To start playing, a trigger button has to be held down while swinging the remote in a similar way to actual bowling, and once the trigger is released the virtual avatar lets go of the ball. Likewise, the Tennis game invites the player to participate in different matches, using the Wii Remote as racket that has to be swung at the correct time to return the ball. In Golf players are asked to hold the remote with both hands, using it as a golf club. Boxing allows players to compete against each other while using the Nunchuk extension in addition to the Wii Remote. Holding each of the controllers in one hand, players can imitate boxing movements to steer the avatar. The games include typical game features such as avatars to represent the player, a complex scoring system that tracks personal improvements and allows for competition between players, and player rewards.

Similar games have been released for the Microsoft Xbox and its Kinect sensor [Microsoft, 2010], which utilizes an infrared-based time-of-flight camera. Players are not required to hold any kind of controller but can move around freely within a certain distance of the camera. Sony's PlayStation Move controller [Sony, 2010] combines both technical approaches. The controller is equipped with accelerometer sensors and comes with a light bulb that is tracked by a camera system. Generally, there are two different types of games: (1) using the controller is an additional feature of many games that were designed to be played with a traditional gamepad, such as Tiger Woods PGA Tour. (2) A number of games that require the controller have been released that feature mechanics that were specifically designed for movement-based player input. Examples of such games range from Eyepet and Friends, a game in which players are invited to take care of a virtual pet, to traditional role-playing games such as Sorcery, in which the controller is used to interact with the virtual environment by casting gesture-based spells.

3.1.2 Academic examples

Human Pacman ("Pacmanhattan,") is one of the earlier academic projects concerned with physical player input in games. The augmented reality mobile game transfers the principles of traditional Pacman — a game in which the player has to collect coins while racing from ghosts — into the real world. Likewise, Age Invaders [Khoo et al., 2007] — a mixed-reality version of the traditional Space Invaders game in which aliens are invading Earth and have to be shot — tries to engage multiple generations (children, parents, and grandparents) in play and requires physical activity as players are expected to move around on the playfield. Efforts have also been made in the field of accessible game design. Morelli et al. [2010] have integrated the Wii Remote controller in different games so that they are accessible to players that are visually impaired. VI-Bowling is an accessible version of Wii Sports bowling that uses audio as well as tactile information to allow people with visual impairments to engage in bowling play. Similarly, work by Gerling et al. [2016] explores the idea of exertion games for players with physical impairment, investigating the benefits of play for young people using powered wheelchairs in a context that does not require much physical effort, yet enables players to engage in physical play. Results show that movement in games can have a positive impact on players regardless of exertion, outlining the design opportunity that these games offer.

In summary, exertion games that come from a traditional digital game background and incorporate exertion typically aim to facilitate an engaging user experience without primarily aiming to provide vigorous levels of exertion. These games focus on gameplay and implement activity to supplement that goal. The popularity of such games has largely increased with the release of Nintendo's Wii, which was followed by the release of a growing number of commercial games employing physical effort as user input. This was supplemented by academic studies investigating the various effects of playing these games.

3.2 In-between exertion games

Moving away from the strong focus on gameplay, in-between exertion games "aim to balance physical activity and gameplay to provide the user with an engaging gaming experience while ensuring that physical player activity leads to significant levels of energy expenditure" [Gerling and Mandryk, 2014]. Besides commercially available games for different console platforms, systems using special hardware have been released, and academic research has also explored their potential.

Generally, creating an engaging gaming experience is as important as fostering significant physical activity for yielding potential benefits to the player. Game elements and physical activity are often closely tied together instead of being treated as mere add-ons.

3.2.1 Commercial examples of in-between exertion games

One of the earlier examples of commercial in-between games uses foot-based input: the Bandai's Power Pad was released for the Nintendo Entertainment System console in the 1980s. Players interact with a range of games through a mat largely resembling the input device for Dance Dance Revolution. The game uses a custom controller, a mat equipped with sensors to detect the player's steps, and invites players to dance along to different songs, displaying necessary moves on-screen. Because of the fast pacing of the game and increasingly difficult dance moves, the game aims to encourage higher levels of energy expenditure than the games described earlier. However, it also focuses on providing a positive player experience and integrates different gameplay elements (for example, continuous feedback, a scoring system and a multiplayer mode) that go beyond providing an augmented dancing experience. Another example of a game controller integrating foot-based interaction is the Nintendo Wii Balance Board. Nintendo Wii Fit, its release title, features different yoga and muscle workouts as well as a series of mini games that aim to improve the player's balance. While the aspect of sports is emphasized for the workout part of the game, many of the balance games combine physical activity with gameplay, encouraging the player to participate in playful activities. One of the first commercial systems using a camera-based approach towards tracking user input is Sony's Eye Toy webcam [Larssen et al., 2004]. By tracking user movements within a certain range, the camera can be used to control game content, many with a relatively strong focus on providing an intense workout, such as Sony EyeToy: Kinetic Combat. Likewise, the Microsoft Kinect sensor [Microsoft, 2010] has been used in the design of games that utilize the user's whole body as the input device, for example, games that require players to jump (for example, Kinect Adventures [Wikipedia contributors]). Furthermore, a wide range of commercial games requiring special hardware or sports equipment has been developed. Many of these games resemble arcade systems as they provide a complete gaming setup, such as the Cat-Eye GameBike [Gamebike, n.d.] integrating a stationary bike with different racing games designed for Sony's PlayStation, or the GameCycle system, which combines playing racing games with an upper body workout using a hand bike.

3.2.2 Academic examples of in-between exertion games

Apart from these commercial games, a range of studies exploring game design has been created in academia. To further differentiate between different types, we make the following distinctions: First, we give an overview of stationary games using either sports or gaming equipment as input devices. Second, we present mobile games that were designed to be played in an outdoor environment. Finally, we provide an overview of games using physiological information — usually heart rate — as primary player input.

Stationary exertion games are games that do not require the player to move around in order to work out, instead using treadmills, stationary bikes, or sensor-based systems to track physical activity in one location. One of the first examples of stationary exertion games is the system Virku Mokka et al. [2003]. It uses a stationary bike in combination with a large display in order to simulate a biking environment. Players are challenged to participate in racing games. Difficulty adjustments are made based on the terrain displayed in the racing game, for example, if the player has to bike uphill, the resistance is increased. The game features a multiplayer mode that allows two users to compete against each other. Also implementing stationary bikes as input devices, Göbel et al. [2010] designed different games based on an authoring framework that allows for the modular combination of different in-game challenges in order to create games that individually adapt to player preferences and fitness levels. The authors present a number of sensor-based mini-games that support stationary play, for example, running in place using accelerometers in SunSportGo, a game that combines physical and mental challenges similar to biathlon.

Life is a Village Yim and Graham [2007] is another example of an exertion game using bike-based input. The authors implemented a recumbent bike in combination with a game pad to allow the user to interact with the game world. In contrast to other case studies, they do not combine these input devices with a racing game, but instead implemented a virtual environment in which an avatar — a villager — is controlled through physical user effort. The game features different goals that were designed to foster both short-term and long-term player motivation. The overall goal of the game is to build a village: To accomplish this objective, the player needs to collect different resources, which allow her/him to create different buildings. This requires the player to advance through the game world, explore different areas, and harvest resources that then need to be transferred to the village. Also implementing traditional sports equipment as user interface, the system Exertainer Ahn et al. [2009] was designed to entertain people running on a treadmill in combination with accelerometer information. The authors present the case study Swan Boat, a multiplayer game in which users attach accelerometers to their wrist in order to track hand and arm gestures, and running on a treadmill is processed as input in order to track collaborative efforts towards steering a boat on its way down a virtual river. A two-week user study with 17 participants comparing running on a treadmill to running and playing Swan Boat showed that players enjoyed engaging with the game.

One of the earliest academic-driven examples of exertion games is PingPongPlus by Ishii et al. [1999]. The game uses a sensor-enhanced camera system to track how users interact with a regular table tennis table. While its basic mode that only highlights the ball's impacts on the surface could be considered an augmentation of sport, the game also features a "PacMan-mode": This includes a scoring system as well as a competition around projected power ups that players need to hit in order to increase their score, therefore making it an exertion *game*. Kick Ass Kung-Fu by Hämäläinen et al. [2005] is a fighting game that brings together martial arts and video games. The game uses a camera-based tracking system to allow for a variety of kicks and jumps. Feedback is provided through three large displays; users compete against stylized virtual characters, and learn about their performance through health bars and on-screen notifications similar to regular fighting games. An evaluation with 46 martial arts practitioners showed that Kick Ass Kung-Fu is perceived as a game that is engaging and fun to play. Additionally, the evaluation revealed that the game provides a challenging workout and might serve as training tool for beginners. The casual game GrabApple by Gao and Mandryk [2011] is based on the idea of providing players with short, 10-min chunks of exercise to help them obtain the recommended amount of 30 min of daily exercise at moderate-to-vigorous intensity levels. The authors argue that allowing for short gaming sessions helps players fit exercise into their daily routines whereas adding a playful dimension will help increase user motivation. A user study with eight participants showed that the game was perceived as entertaining, and it revealed that it induces moderate-to-vigorous levels of activity in users.

Research by Sheinin and Gutwin [2014] opens up new perspectives on in-between exertion games, exploring whether small-scale exertion (that is, exertion of the fine motor system, for instance through repeated button-pushes) can contribute to appealing player experiences that build on physical endurance, thereby reintroducing physical activity into previously sedentary sports video games.

Several research projects in this category focused on mobile sensing. For example, Fish 'n' Steps by Lin et al. [2006] introduces an asynchronous game concept combining sensor-based tracking of user activity throughout the day with the task of taking care of a virtual pet: Players wear a pedometer to count the number of steps they take. Once they synchronize this information with their computer, their pet grows if a certain step goal is achieved. Additionally, the facial expression of the virtual pet changes based on overall player activity to provide additional feedback. A 14-week long user study with 19 participants investigating the effects of Fish 'n' Steps on the number of steps taken by the participants showed that their step count could be increased by drawing attention to basic activity throughout the day, and that this increase prevailed in the post-intervention phase of the study. In addition to that, participants reported that taking care of the fish was perceived as fun and engaging. A similar approach is followed by the game Gemini, which was designed Stanley et al. [2011]. The role-playing game is based on the Neverwinter Nights 2 Aurora toolset and combines physical activity of players throughout the day with in-game rewards. Player activity is determined based on different sensors (accelerometer information, temperature and light sensors), and is then transferred into the game world by increasing the strength of the player's animal companion depending on daily activity levels.

Other than these approaches that rely on accumulated information on player activity using an asynchronous approach to combine exercise with gameplay, a number of case studies have been implemented on smartphones to allow players to synchronously experience exercise and participate in play, providing realtime gameplay and immediate feedback on physical activity. PiNiZoRo by Stanley et al. [2010] is a location-based mobile game using GPS information. It was designed to encourage families to explore the outdoor world. The game tells the story of an ancient conflict between pirates, ninjas, zombies, and robots, and thereby tries to engage children who play the role of detectives or spies and have to battle the infiltration of their neighborhood by these creatures. In contrast to other exertion games, PiNiZoRo tries to balance story, gameplay, and exertion to increase the long-term motivation of children, who have to use maps to find secret hideouts and walk around outside to engage in combat mini-games. In order to involve parents in the game, they are given the opportunity of creating new maps for their children to explore. Results of a preliminary study show that the concept appeals to parents; however, an evaluation with children has not been conducted yet. The project by Prévost et al. [2009] follows a similar approach. The authors present a pervasive role-playing game in which players collect flowers along the Kamo River in Japan. The game combines in-game challenges and spatial aspects, requiring players to search their physical environment or reach different locations to fulfill quests provided by the game. Kiili et al. [2010] designed two games that can be played on mobile phones to foster activity among children and teenagers. Their first game, Tuck of War, is designed as a multiplayer game in which players of the opposite team have to be pulled into a gap. Players have to perform squatting movements to interact with the game, and the number of squats per team is used to determine the overall outcome. Diamond Hunter is their second game and follows a different approach. Up to four users can participate in a 2D platform game with automatically moving player characters. Players have to jump in order to make their in-game character jump up and collect as many diamonds as possible. An evaluation of both games showed that participants enjoyed engaging with them, particularly highlighting exertion elements. Furthermore, the evaluation revealed that participants appreciated collaborative play. Görgü et al. [2012] suggest the term freegaming to refer to exertion games that are supposed to be played outside and implement sensor technology to integrate the player's body as input device.

Besides these exertion games using traditional input devices, a growing number of games have been integrating physiological user input, mainly sensing the user's heart rate in order to balance or influence in-game challenges and to monitor exercise efforts. In the game Health Defender, Wylie and Coulton [2008] leverage the player's heart rate to award bonuses if a predefined target heart rate is met. The game is based on the idea of Space Invaders, and players have to use the keyboard to fight viruses that are entering each level from the top of the screen. Focus group results show that players would prefer the integration of heart rate information in more important areas of play than to determine bonus distribution only. Such an approach has been done by several other case studies in the field of physiological interaction and games. In order to replace input devices that require a certain type of exercise, Nenonen et al. [2007] introduced heart rate as user input in order to allow users to freely choose workout routines to influence their heart rate and thus make an impact on the game. In their case study Pulse Masters Biathlon, players are challenged in a biathlon race. In order to accelerate while cross-country skiing, users have to increase their heart rate. However, increasing it too much will result in difficulties when presented with shooting tasks because a heart rate above the recommended target rate will lead to decreased accuracy, thus users have to balance their exercise efforts. A user study revealed that participants were able to interact with the game through their heart rate, showing that intentionally manipulating one's heart rate can be implemented as user input successfully. Stach et al. [2009] further explored the use of heart rate to control games by introducing scaling mechanisms that allow users with different fitness levels to play together. The authors present the case study Heart Burn, a racing game that is controlled through game pad input and exercise on a recumbent bike. A study showed that performance scaling based on heart rate information (that is, factoring in whether the player was close to their target heart rate) reduced the gap between players with different fitness levels without having a negative impact on user engagement during play. Masuko and Hoshino [2006] suggested an exercise system in which the user performs different boxing movements such as punches, upper cuts, hooks, or weaving, that are tracked using a camera-based system. In addition to these movements, the user's heart rate is sampled in order to ensure exercise effectiveness by comparing the current rate to the user's predefined target heart rate, and to adjust in-game challenges accordingly. As a case study, the authors present a fighting fitness game in which the player controls a dragon that has to defeat a monster. To achieve this goal, players have to perform boxing movements to reduce the life energy of their opponent. Based on heart rate information, the monster's behavior is adapted. That way, the authors try to adequately challenge the player based on and in order to influence the heart rate.

There have also been efforts towards the design of exertion games for special audiences. Hernandez et al. [2012] present a gaming platform for children with cerebral palsy, who experience difficulties in being active due to the effects of their disease. By combining a custom designed stationary bike with traditional game controller input, the authors provide an accessible gaming platform, which encourages workouts. Astrojumper by Finkelstein et al. [2010] is a space-themed game targeted at children with autism. It aims to engage players in simple movements while focusing on the main challenge of the game, avoiding collisions with different objects in space. The game is implemented in stereoscopic 3D and designed to be played in a virtual reality cave using a tracking system to follow user movements.

In summary, as a result of the increasing availability of affordable input devices that support physical activity, an increasing number of exertion games have emerged that aim to create a balance between gameplay and physical interaction. Thereby, new opportunities to create physically engaging play are opening up, allowing researchers and designers to create new experiences that have potential to appeal to players with an interest in games and sports alike.

3.3 Augmented sports

Augmented sports primarily build on physical activity, and are designed to foster moderate to vigorous exertion. While the activity itself and the related actions represent the core of the augmented sports games, game elements are introduced to improve the user's overall experience. This approach is closely related to the idea of gamification, which refers to the inclusion of game elements in a non-gaming context in order to support an enhanced user experience [Deterding et al., 2011]. According to Gerling and Mandryk [2014], augmented sports are "activities that primarily focus on providing users with exertion or foster motor learning and rely on information technology to supplement this goal." Augmented sports applications typically do not focus on offering an engaging gaming experience through the inclusion of complex game mechanics, but rather extract a few desirable game features to support user motivation and learning processes.

3.3.1 Commercial augmented sports exertion games

The most popular augmented sports exertion games in the commercial realm are probably occurring in the form of sports apps that run on mobile phones these days. Most of them support joggers, with a plethora of apps that are available. Most of them track the jogging activity, recording pace, and distance, however, they almost all involve the ability to compare results, either with oneself or with other sports people, allowing for competitions and hence are supporting at least this particular form of play. For example, Nike [2012] introduced Nike+, a framework for tracking running exercises based on sensor information, which can be fed into a social network that allows users to review exercise routines, display exercise achievements to friends, and compete with other users across different challenges. Similarly, the social network [Fitocracy, 2012] builds on this idea and lets users track their exercise routines. It provides points based on the self-reported scope of the workout while player achievements are displayed on leaderboards. Furthermore, the platform offers different quests to encourage users to compete for additional points, and can be connected to social networks in order to share personal achievements with friends.

3.3.2 Academic examples of augmented sports exertion games

Many augmented sports exertion games from the research field are concerned with the extension of regular outdoor sports with digital means. An approach towards the creation of shared running experiences is Jogging Over A Distance by [Mueller et al., 2010b,c]. It connects two athletes in different locations by implementing heart rate information and spatial audio feedback: Runners provide their preferred heart rate, and depending on how close to it they exercise, audio transmission between both participants seems to come from a close or distant location. A user study showed that the combination of social interaction and exercise was well-received. Fitness Tour by Chuah and Sample [2011] is a mobile application that generates random routes through cities for users to follow. To provide feedback on calorie consumption, Fitness Tour prompts users at certain points of their run to press their finger against the camera, which allows the authors to sample heart rate information. TripleBeat de Kort and IJsselsteijn [2008] is a mobile application designed to support running. The application uses heart rate information to evaluate exercise efforts and provides audio feedback on running performance by selecting slow or fast songs from the user's music library. Furthermore, it implements a graphical user interface that presents physiological data to provide the user with information on heart rate and energy expenditure. Additionally, it reveals the user's position relative to other runners if the user decides to engage in a competition prior to the start of the exercise. An evaluation with 10 participants showed that users particularly enjoyed competitive elements and reported that the application increased their exercise motivation. Another slightly different approach towards augmented outdoor sports experiences is the skateboarding game Tilt 'n' Roll by Anlauff et al.

[2010], which requires users to ride a skateboard that is equipped with sensors to detect board movements and tricks. This setup is extended by a mobile application that keeps track of user achievements. Similarly, Copy Paste Skate also supports skateboarders through interactive technology [Pijnappel and Mueller, 2014]. Misund et al. [2009] present another case study with a strong focus on playful aspects. The authors augmented traditional children's games such as chase-and-catch or fox hunt with mobile applications to track user positions and to include a scoring system.

In contrast to augmenting outdoor activities, another subset of augmented sports focuses on indoor activities. Sports equipment such as treadmills or stationary bikes are hooked up to computer applications to simulate the real-world experience, for example, running on a treadmill would be augmented by displaying an outdoor environment on a computer screen, adjusting the pace of the world passing by to the speed of the athlete. Such an approach is used in Virtual Active [2012], a video-based extension of treadmill running. When working out on the treadmill, users can choose from different videos showing interesting scenery such as famous cities, historical sites, or nature. Videos are played back from a first person perspective and in accordance with the user's running speed. One of the earliest examples in this field is a shared walk environment presented by Yano et al. [2000]. The collaborative environment connects users in remote locations and was designed to facilitate physical therapy, particularly teaching people how to walk, by allowing participants at one end to supervise the walking style of remote users. To track user input, the authors implemented a locomotion interface similar to a treadmill in combination with an optical tracking system that facilitates the assessment of user movements. Peloton, an application designed by Carraro et al. [1998] uses treadmills or stationary bikes as input to simulate courses for jogging and biking. The software was designed to provide a foundation for web-based collaborative exercise sessions and to foster competition between athletes in remote locations.

RunWithUs by Gil-Castiñeira et al. [2011] was designed to promote physical activity, particularly jogging. The application uses the local Wireless LAN infrastructure to keep track of user positions and consists of two core elements: RunWithUs tracks and analyzes user statistics to provide feedback on workout sessions, and it comprises a social component that allows users to interact with friends, form teams, and view group sessions. In contrast to these applications designed to foster intense physical workouts, there are also approaches such as UbiFitGarden [Consolvo et al., 2008] that aim to foster general activity by visualizing daily activity levels through a playful virtual garden displayed on the phone's wallpaper screen.

To conclude, applications in the field of augmented sports aim to augment the user's experience through additional means, some of which contain game elements, but keep the focus on the actual sport in which users engage. Therefore, the focus on providing rich gameplay is often limited; in contrast, digital games that incorporate exertion come from a digital games background and therefore often feature rich gameplay. We also articulated games that sit in-between these extremes on the exertion game spectrum in order to highlight the rich variety of games that exist in the field. As such, we have provided a view on what types of exertion games exist so far. To complete our understanding of exertion games, we present theoretical approaches around exertion games that in particular are concerned with the design of exertion games and the creation of future games. Therefore in the following section we look at bringing the field forward.

4

Theoretical Approaches Towards Designing Exertion Games

There are several research works that are concerned with movement-based input in general, and exertion in particular, that have led to theoretical models as well as frameworks for the design of technology around exertion. The following highlights a few key works that contribute to an overall conceptual understanding of exertion in HCI. We conclude this section with the Exertion Framework, which we describe in a bit more detail, as we use it to structure the section that follows on implementation technologies.

Larssen et al. [2004] found that increasing physical effort in games can enrich the user experience. Research also discovered that participants in exertion games perceived their exertion not as high as without the game, even though their heart rate was the same [Fogg, 2002]. Bianchi-Berthouze et al. [2007] found that increasing exertion leads to higher levels of arousal and positive experiences in games. Although these works highlight the benefits of considering exertion, there is still a shortage of empirical studies that investigate exertion experiences across a range of rich interactions [Moen, 2006]. This could be attributed to the technological challenges in designing these games:

studies of exertion games identified that there are still many technology limitations when it comes to incorporating exertion [Smith, 2005]. Such limitations — for example, insufficient accuracy in sensing the moving body — can significantly impact the user's experience [Smith, 2005]. One way towards better games seems to be addressing the technical challenges, however, another complementary way is to deal with the limitations of the technology by means of smart design [Consolvo et al., 2006, 2008]. Smart design can be guided by conceptual frameworks, however, most existing frameworks such as by Salen and Zimmerman [2003a] and Koster [2004] are generic to digital button-press games and therefore miss out on considering the opportunities exertion games offer. For example, Larssen et al. found in a study of a camera-based game that players performed movements that were not needed for the game, but were nevertheless suited to the context of the game Larssen et al. [2004]. The authors refer to Bower & Hellstrom's [2000] notion of expressive latitude that allows for rest and physical performance to explain what happened. Computer gamers do not usually need to rest from physical exhaustion, nor do they commonly perform movements that are not necessary for the game, hence a framework oriented on button-press games would have missed these aspects of the user experience.

Bogost's [2007] work on how exertion games convince people to exercise also points to another difference in regards to frameworks between exertion games and button-press computer games: In conventional computer games, designers usually build the goal players need to achieve into the game [Pagulayan et al., 2003]. Even if there is no explicit goal, such as in the Sims series [Electronic Arts, 2010], the designer of the game provides opportunities for players to create goals that are still imbued with value from within the game. However, in exertion games the context within which exertion games are played can be another source for goals that the designer might need to consider. He found that successful exertion games couple the game's points system with the player's own goals, such as completing an exercise routine [Bogost, 2007, p. 311]. Smith points to additional contextual aspects unique to exertion that might get lost when seen from a traditional framework's perspective: he suggests, for example, that designers of exertion games incorporate warm-up exercises to reduce the risk of injury [Smith, 2005].

Loke et al. [2007] tried to understand movement-based interactions and concluded that a comprehensive framework is still missing. The framework proposed by Fogtmann et al. [2008] aims to reveal the bodily potential in HCI by highlighting the different ways human bodies can interact with each other in exertion games: They can encounter either a joint or opposed "kinesthetic empathy interaction" Fogtmann et al. [2008].

Based on research through design experience, prior work has also resulted in guidelines for movement-based games [Mueller and Isbister, 2014]. These guidelines, validated by experts, propose to consider three unique categories when designing movement-based games: "Movement requires special feedback," "movement leads to bodily challenges," and "movement emphasizes certain kinds of fun." These categories contain specific guidelines: the authors suggest to designers to "embrace ambiguity" when it comes to feedback, "celebrate movement articulation" concerning the secondary performance aspects of movement, "consider movement's cognitive load" to not overload players with feedback and "focus on the body" rather than the digital, for example, a screen. Furthermore, the authors highlight the bodily challenges and suggest to "intend fatigue" rather than let it occur incidentally, exploit the physical "risk" that comes with exertion, and map movements "imaginatively" rather than slavishly true to life. Lastly, the guidelines highlight "certain kinds of fun": designers should "highlight rhythm" in movement, "support self-expression" through movement and facilitate the "social fun" that comes from moving together.

Another popular framework for exertion games comes from psychology: the self-determination theory [Rigby and Ryan, 2011] aims to make the experience more engaging by satisfying the innate psychological needs of humans. These innate psychological needs can be classified into three categories: (1) competence, (2) relatedness, and (3) autonomy [Rigby and Ryan, 2011].

(1) *Competence*: Competence refers to the innate desire to grow our abilities and gain mastery over new situations and challenges. Competence is often achieved by setting a challenge and reward structure

around the activity and making the progress of the activity visible. For example, devices such as heart rate monitors and pedometers give real-time feedback on the exertion activities and how well the user is performing in relation to set health goals. Many exertion games aim to support competence through rewards, such as virtual points and leaderboards.

(2) *Relatedness*: Relatedness refers to the need to have meaningful connections with others with a sense of belongingness and a feeling of camaraderie. For example, social applications such as RunKeeper allow users to keep track of their physical activities as well as share the statistics with others. Competitive and collaborative multiplayer exertion games are other examples that aim to capture relatedness through group and shared exertion activities [Park et al., 2012]. Goodgym is another example that captures relatedness through a social purpose; with GoodGym, joggers are motivated to help the elderly by providing them grocery items such as milk which they promise to deliver on a regular basis.

(3) *Autonomy*: Autonomy refers to the innate desire to take actions due to personal volition and not external influence or control. Autonomy is achievable by giving the user freedom and scope to vary the activity within its set boundary. Users can feel autonomous if they have the liberty to choose their exercise routine and set their health goals. Digital games are particularly known to provide autonomy by giving users meaningful choices and freedom to act within a virtual game world [Rigby and Ryan, 2011]. Physical sports and performance-based arts such as dance and body sculpting leverage autonomy through self-expression.

Unfortunately, physical exercise often does not give a true sense of autonomy. For example, an individual should not only exercise regularly but also at the appropriate level of intensity. This would involve setting up an exercise routine (which also means repeating similarly structured exercise everyday and doing so for the rest of one's life) and obeying rules instructed by a physician or coach. This can be perceived as experiencing limited autonomy. Therefore, we seen an opportunity for the digital element of exertion games to offer users options to take actions out of personal volition.

Furthermore, exertion games often pre-tailor the activity and hence reward players only when following exercise instructions correctly and in order. For example, in many exertion games there is a predefined mapping between bodily movements and actions inside a game. If the player does not make the correct body movement at the correct time, there is no defined action within the game. As a result, many unmapped bodily movements go unnoticed inside a game. This can limit experiences of autonomy by failing to provide users with options for self-expression and creativity. Interestingly, it has been observed that when an activity does not provide users with any option for creativity, they often alter their actions to make themselves feel autonomous and creative. For example, runners tried to be creative with their running patterns, tracked by a mobile phone app on a virtual map by deliberately running in a pattern that resulted in "jogging art" [Dickson, 2014].

4.1 The exertion framework

Mueller et al. [2011] presented an exertion framework in order to help designers creating exertion games. The framework begins with an appreciation of the central role that the body plays in such experiences by placing it in the center of the framework, surrounding it with four concentric "onion-like" layers around it that describe four different lenses through which the designer can see the exerting player. These layers are supplemented by a set of themes, and the designer can look at these themes through each of the layer lenses (Figure 4.1).

4.1.1 Four lenses on the exerting player

The four lenses are: The responding body, the moving body the sensing body, and the relating body.

4.1.1.1 Lens 1: The responding body

The responding body is a view of the body "from the inside," or how the body's internal state changes over time. The body reacts to physical activity by responding internally in a way that maintains balance, or

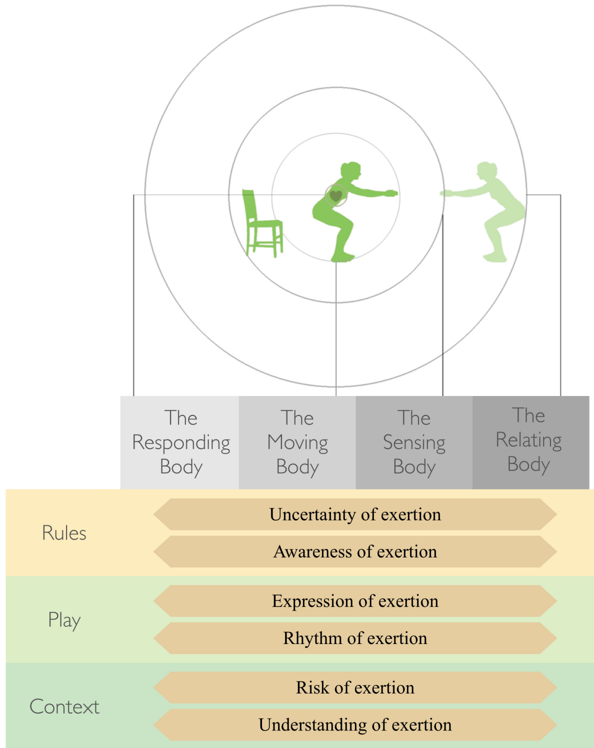

Figure 4.1: The Exertion Framework based on Mueller et al. [2011].

"homeostasis" [Plowman and Smith, 2007]: the user's heart rate typically increases, breathing becomes more frequent, and sweating occurs. The body responds not just in anticipation of and during exertion, but also after such activities: a participant might lift more weight on further exposures to the same exercise as a consequence of becoming stronger. However, the body's response is not always a positive experience, for example, users might become aware of their bodies' response through muscle soreness or injury.

4.1.1.2 Lens 2: The moving body

The moving body focuses on players' muscular repositioning of body parts relative to one another during the course of physical activity.

The moving body therefore highlights the kinesthetic sense, or proprioception, which governs users' awareness of the position of body parts [Moen, 2006].

4.1.1.3 Lens 3: The sensing body

The sensing body describes how the body is sensing and experiencing the world. This perspective differentiates exertion games from conventional sports in that the world of exertion games consists of both physical and virtual objects and spaces.

4.1.1.4 Lens 4: The relating body

The relating body encompasses the ways in which players relate to one another through digital technology. Such social interactions are highly diverse, mediated by a wide variety of roles such as co-players, opponents and audiences [Sheridan and Bryan-Kinns, 2008] while joint exertion can contribute positively to social outcomes [Lindley et al., 2008, Strömberg et al., 2002, Wakkary et al., 2008].

4.1.2 Six schemas across the four lenses

The Exertion Framework borrows gaming schemas from game literature: rules, play, and culture [Salen and Zimmerman, 2003a]. These schemas are used to group concepts that are meant to be considered through each of the four body lenses.

4.1.2.1 Rules: Uncertainty of exertion

Uncertainty contributes to an element of suspense and facilitates surprise in games through chance events, which can play an important part in what makes a game engaging [Benford et al., 2003]. In conventional button-press computer games, most chance encounters need to be artificially introduced through explicitly programmed code. In exertion games, on the other hand, uncertainty can also arise through the body. The body's response to exertion is hard to predict for player and technology alike ("how long can I keep up?"), and the variety of bodily movements can cause even simple actions to go wrong (for example, missing a free-throw in basketball or a short putt in golf). The concept "uncertainty of exertion" makes designers aware that they need to manage the relationship between the uncertainty arising from the body and the programmed uncertainty in the virtual world.

4.1.2.2 Rules: Awareness of exertion

In exertion games, players often aim to overcome the limitations of their bodies, for example, wanting to jog further and faster. The advantage of introducing computers to this bodily struggle is that digital technology can selectively hide bodily information from players as well as reveal it [Reeves et al., 2005, Salen and Zimmerman, 2003b] so that the player can then benefit from both increased and decreased awareness of their exertion. For example, facilitating a person's awareness of physical effort can foster competitions [Consolvo et al., 2006] or design can focus on distractions such as playing music [Karageorghis and Priest, 2008].

4.1.2.3 Play: Expression of exertion

Exertion as a form of self-expression highlights the richness and expressive power of the human body [Bianchi-Berthouze et al., 2007, Bowers and Hellstrom, 2000, Larssen et al., 2004, Sheridan and Bryan-Kinns, 2008] affording performative interactions [Hornecker and Buur, 2006, Sheridan and Bryan-Kinns, 2008, Sheridan et al., 2005]. Performative expression using the body is common in sports, often in the form of gestures such as "throwing fists" to the opponent, and celebratory dances. Although such actions require the expenditure of bodily energy and hence one might come to the conclusion that they do not support making progress towards the goal of the game, they can significantly contribute towards the experience [Bianchi-Berthouze et al., 2007, Larssen et al., 2004].

4.1.2.4 Play: Rhythm of exertion

Rhythm of exertion is about the ability of a system to support a uniform or patterned recurrence of a beat in bodily action. Rhythm in movement can exist within movement itself, but is often associated with music and exercise. It has been shown that the rhythm of music during exertion activities can regulate arousal, improve athletic performance, positively impact the acquisition of motor skills and dissociate from the discomfort of exercise [Karageorghis and Priest, 2008].

4.1.2.5 Context: Risk of exertion

Risk of exertion highlights the vulnerability of the body to overexertion and injury. However, exposure of the body to risk in sport is different to risk-taking in computer games [Salen and Zimmerman, 2003b]. In computer games, risk is virtual, as most actions can be "undone" easily [Klemmer and Hartmann, 2006]. In contrast, bodily vulnerability can lead to a constant preparedness for danger and surprise, and this readiness shapes one's life experience [Dreyfus, 1991].

Figure 4.2: One of the exertion game cards.

4.1.2.6 Context: Understanding of exertion

Understanding of exertion refers to the potential of a system to support the development of knowledge about the body. For an understanding of the exerting body two key aspects come to the fore: knowledge and skill [Kretchmar, 2005]. Knowledge refers to the theoretical understanding of the body, for example, heart rate monitors facilitate knowledge about one's anaerobic and aerobic zones and hence about understanding one's body. Skill on the other hand allows people "to do things," and is gained predominantly through training and practice [Kretchmar, 2005].

4.1.3 Exertion cards

The Exertion Framework has been transformed into design cards to offer the more abstract nature of the framework's concepts into more colloquial "things to think about" questions that designers can relate to [Mueller et al., 2014b]. The idea behind such design cards is that they can be introduced to a design process in order to offer guidance. These Exertion Cards have been successfully used in workshops with student game designers as well as industry designers [Mueller et al., 2014b] and they are available for free online.

Each card features a provocative question that is aimed to provoke creative design thinking. Each card also features a dimension aspect to each question, highlighting that adding themes to a design idea is not a simple yes or no decision. The cards also have two pictures on them that represent examples of either end of the dimension. An example of a card is below (Figure 4.2).

The title of each card and associated question is detailed in Table 4.1.

Table 4.1: The card titles and associated questions.

Card	Provocative question
Physical risk	To what extent is physical risk considered?
Movement variety	To what extent can players explore the many ways of movement to achieve a goal?
Secondary performance	To what extent can players use their bodies to communicate outside the game?
Intensity interpretation	To what extent is intensity interpreted?
Continuousness interpretation	To what extent are pre-movements and follow-throughs interpreted?
Effort interpretation	To what extent is physical effort interpreted (in contrast with performance)?
Bodies in harmony	To what extent does the game encourage bodily synchronization?
Fidelity of mapping	To what extent are movements mapped from the physical world to the virtual world?
Exhaustion management	To what extent is managing exhaustion part of the game?
Haptic feedback	To what extent does the virtual world offer feedback on the body?
Tangibility	To what extent can the player master the control of objects (like a ball)?
Physical contention	To what extent can players share space, an object or their bodies in the physical world?
Virtual contention	To what extent can players share space, an object or their bodies in the virtual world?
Integrated communication	To what extent does communication affect the virtual world and vice-versa?

5

Implementation Technologies

Designing exertion games means considering interactive technologies. As with any interaction design, the use of technologies offers not only opportunities but also challenges. In this section, we describe the key implementation technologies, not so much to provide a complete account of how to sense exertion, but rather to articulate a categorization of the most common technologies and how they can support the four layers of the exertion framework described earlier. We then describe a set of properties that we articulate for each technology across the layers in order to highlight opportunities and challenges of the aforementioned technologies.

5.1 Technologies for the responding body

When it comes to supporting the responding body with interactive technology, it is common to refer to sensors that measure the body's response to the physical effort invested such as increased heart rate. Heart rate is probably the most common form of measuring exertion intensity, but there are also other ways to gain insight into the "responding body," such as the Borg Perceived Exertion scale as known from sports science [Borg, 1998]. With this scale, participants are asked to rate their perceived exertion. Although not a sensor in the technical sense, exertion game designers could use this scale to ask players about their perceived exertion in order to inform gameplay, in fact, studies show that rating one's own exertion can have a strong relationship with heart rate [Stamford, 1976]. Similarly, the "talk test" stipulates that talking (or singing) gets increasingly more difficult with increased physical effort intensity [Foster et al., 2008]. Exertion game designers could use this knowledge to inform gameplay by analyzing the ability of players to talk: This seems especially relevant in games where microphones are already used, such as in online games.

Sensors that measure biodata are becoming cheaper and more accessible; for example, heart rate monitors have moved from specialized sports science equipment to heart rate belts used by amateur athletes to devices that are incorporated into smartwatches and used everyday. Moreover, advanced analysis techniques can now sense heart rate through cameras [Muender et al., 2016], such as is enabled with the Kinect 2, allowing sensing not just through wearables, but from a distance. Similarly less intrusive sensors have been proposed to gather other biodata [Yingzi, 2011]. However, it is important to note that with the proliferation of these technologies, there is often a reduction in sensor data quality: for example, the heart rate data sensed by a camera is lower than that sensed by a smart watch, which is in turn lower quality than the data from a high-end ECG device. In our experiences with heart rate sensors, we found that the quality of the cheap heart rate sensors can be sufficient for the use in games (as demonstrated by for example, Stach et al. [2009]) however, to make advanced measurements (for example, for training or medical purposes), higher-quality equipment might be needed. Furthermore, it is also important to consider how easy it is to gather the data: for example, although blood lactate concentration is a better indicator of exercise intensity than heart rate [Goodwin et al., 2007], taking blood samples (as required to measure lactate concentration) is considerably more cumbersome than wearing a smart watch. However, advances in sensing technologies will spawn easier ways to sense exertion, and the quality of the sensed data will also increase. We encourage exertion game designers to gather the necessary knowledge to interpret the higher-quality data that these advanced systems will offer in easier ways and explore how this can effectively be utilized in future game design.

5.2 Technologies for the moving body

Supporting the moving body most often refers to sensing limb movements. There are two key implementation approaches: through cameras that capture and track limb movements, or through attaching sensors (such as inertial measurement units (IMUs) or flex sensors embedded into clothing) to the players' limbs. Both approaches have advantages and disadvantages. A camera-based system allows the body to freely move around unencumbered (many motion-capture systems do require users to wear special markers though to improve the tracking of the limbs). However, any camera needs to be able to see the limbs, and therefore these systems often encounter challenges when it comes to occlusions and changing lighting conditions. IMUs worn by a player do not have these shortcomings, however, they can suffer from drift — that is, an ever-increasing difference between where the system thinks the limb is located and the actual location. Furthermore, camera-based systems can sense more than one limb; in contrast, IMU-based systems need one sensor for every limb.

5.3 Technologies for the sensing body

As the sensing body is concerned with the body interacting with its environment, including any surrounding objects, there are many technologies available that can sense these interactions. For example, people have embedded sensors in playing equipment like balls [Izuta et al., 2010] and in the built environment [Hoonhout and Fontijn, 2008]. Sensors in objects and the environment do not sense exertion per se, but rather the movement that leads to exertion. Movement can be detected with relatively simple sensors. Of course interactions with objects and the environment can also be sensed with the same technology mentioned under the moving body; however, from our experiences, embedding sensors into objects and the environment is often easier and more cost effective. However, with these advantages comes a reduction of generalizability, that is, augmented objects often only support one particular game and therefore different objects need to be designed for different games.

Designers interested in using technology to support the sensing body are advised to look at the literature around tangible interactions, as it has listed a range of sensing technologies that can also be useful for exertion games. In particular, entire toolkits exist to support such tangible interactions [Shaer and Hornecker, 2010], and exertion game designers might profit from examining these. It is important to note that although we believe designers can learn from these tangible sensing technologies, they were most often designed to support fine-motor interactions, as many tangible interaction projects focus on hand interactions with smaller objects. As such, these toolkits do not necessarily support the often very intense and forceful interactions exhibited in many exertion games. Technologies that can be readily embedded into objects and the environment while being able to deal with the wide range of often very intense interactions exhibited in exertion games are still only recently beginning to emerge.

5.4 Technologies for the relating body

Technology for the relating body is mostly concerned with sensing bodies in relation to one another. In recent years, various body-worn distance sensors using ultrasound or depth cameras to sense distance between two players came to the market. These sensors have the advantage that they can sense the relative distance between people, supporting a consideration of the interpersonal distance between people that affects their interaction, originally coined “proxemics” by Hall [1969]. The proxemics toolkit [Marquardt et al., 2011] is a development that might be suitable for such game design efforts, as suggested by [Mueller et al., 2014c]. What the proxemics toolkit does not (yet) do, however, is sense body contact between people. Body contact is not an aspect often considered in HCI, however, it can be a prominent feature in exertion games. And as body contact is one of the key considerations of the relating body, technology that can support this should be in the toolbox of enabling technologies available to exertion game designers. In particular, body contact in exertion games can be very intense and brute. Sensing not only if body contact occurs, but also how (where on the body, for how long, at what intensity, etc.) can be one of the key challenges for designers, however we believe it can also facilitate unique novel experiences.

Although most early exertion game examples did not support body contact, more recent games feature body contact, however, do not explicitly sense it. For example, the game B.U.T.T.O.N. [Wilson and Sicart, 2010] asks players to press buttons before their competitors do, allowing for body contact to prevent their competitors to reach their button. Here body contact is encouraged through the rules, but not sensed. In the game Propinquity [Williams et al., 2010] players have to touch each other's legs and arms based on audio and visual indicators. Here, the sensing of body contact is enabled through sensors sewn into the clothing of the players. Another game is Musical Embrace, in which players are encouraged to press their torsos against each other, this is sensed through a set of pressure sensors placed between their bodies [Huggard et al., 2013]. Sensors that can sense body contact directly, that is, not through mediating sensors embedded into clothing and the like, are so far not very common. However, drawing inspiration from sports that sense contact (for example, fencing), we believe more knowledge about these sensing technologies will enable novel and unique exertion game experiences.

5.5 Properties of implementation technologies

We now categorize the implementation technologies along the four layers described earlier (Table 5.1). In order to compare the implementation technologies, we use the following properties

Table 5.1: Properties of implementation technologies.

Property	Responding body	Moving body	Sensing body	Relating body
Typical sensor	Heart rate monitor	Camera	Touch sensor embedded in environment	Touch sensor embedded in clothing
Exertion sensed	Physiological result of exertion	Moving limbs	Movement in relation to environment and context	Movement in relation to other bodies
Cost	Simple heart rate sensors are cheap, more specialized biosensors can be expensive	Cameras with limited field-of view can be cheap, high-grade motion capture systems still expensive	Sensors embedded in environment can be cheap if they only detect touch, more complex interactions are more expensive	Often needs to be custom-made, hence cost varies
Performance	Sensor data can be read at high frequency; however, bodily responses are often delayed (for example, with heart rate)	Sampling rate often only 25/30 fps limiting fast movement sensing	Cameras have a lower sampling rate compared to accelerometers, GPS sensors are often only 1Hz	Sensors that detect bodily contact such as pressure sensors are often crude in terms of sensing complex bodily contact
Movement restriction	Wearing sensors can be uncomfortable, hindering movement while sensors can also get wet from perspiration, affecting performance	Sensors attached to the body can affect movement	Sensors embedded in environment do not restrict movement	Current technologies are mostly mediated through clothing, which present limitations such as limited washability, limited battery size and placement, etc.

(*Continued*)

Table 5.2: (*Continued*)

Property	Responding body	Moving body	Sensing body	Relating body
Robustness and reliability	Often tricky, as sensors move as a result of movement, affecting readings, and perspiration affects sensed data	Accelerometer-based sensors are usually robust and reliable but cameras often have issues with varying light as experienced outdoors	Same as left	Current technologies are often rigid and stiff, contrasting with the malleability of the human flesh, causing conflict (such as the discomfort of wearing a plastic casing close to the skin)
Setup and calibration	Setup in the form of fit-on required for every player	Not much setup required with accelerometer systems. Camera-based systems often require calibration	Not much setup and calibration required	Mounting sensors on body often requires extensive setup to ensure comfortable fit
Scalability	Each person requires their own sensors	Each person requires accelerometer. Cameras can track more than one person; however, for reliable tracking there is often more than one camera per person	Scales more easily to larger number of players as environment can be host for multiple people	Each person requires their own sensors
Portability	Very portable as sensors are worn	Accelerometer-based systems are portable, camera-based systems are stationary	Sensors embedded in the environment make systems not very portable	Wearable sensors support portability

based on the categorization of implementation technologies used Shaer and Hornecker [2010] that we adapted to exertion games:

- *Typical sensor*: What is a typical sensor used for the particular layer, based on our articulation of the various games that exist in the earlier section?
- *Exertion sensed*: What bodily properties are sensed using a particular technology?
- *Cost*: What is the relative cost of the sensing technology?
- *Performance*: Is the system efficient in terms of sampling rate and response times?
- *Movement restriction*: Are the sensors limiting range of movement? To what extent does a sensing technology affect the player's exertion?
- *Robustness and reliability*: Can the system perform for a long period of time? Can the system withstand intense interactions?
- *Setup and calibration*: What is required to get the system in a usable mode?
- *Scalability*: Can the system support an increasing number of players?
- *Portability*: To what extent does the technology support players' in different places?

5.5.1 Thoughts on implementation challenges

We acknowledge that technology poses challenges to the development of the field of exertion games. However, technology also enabled the development and growth of the field, and as such, we advocate a view of technology in exertion games as a constraining as well as an engaging factor. On the one hand, technology can be a constraining factor. Designers are often restricted by technologies that limit their imagination of what is achievable with existing hardware and software. The downside is often that the focus shifts from creating an engaging experience to the task of figuring out which input and output devices can support the desired exertion action. On the other hand, technology can be an enabling factor. New technological advances can also encourage design ideas, leading to novel products and associated experiences. For example, advancement in tracking technologies now allows distributed joggers to have a shared social run together, an experience previously not possible [Mueller et al., 2010b,c]. With new advances in technology, new opportunities for exciting novel exertion games emerge.

6

Design Recommendations

Apart from the case studies presented earlier in this article, the design of exertion games has been approached from a theoretical and in particular analytical perspective, which has led to the compilation of design recommendations. The following section presents an overview, which was derived from theoretical considerations as well as the practical examination of different case studies using both commercially available systems and research projects.

A meta-level approach towards the design of technologies that incorporate physical activity is provided by Consolvo et al. [2006]. Instead of focusing on games only, the authors present general considerations for the design of information technology to motivate physical activity among users. Based on findings from their case study Houston — an application that keeps track of users' daily step counts — they offer four design guidelines. First, users have to receive adequate feedback regarding their activity. This can be achieved by avoiding deceptive measurements that do not accurately represent users' activity levels. Additionally, it is important to provide sufficient information for users to explore reasons for certain amounts of daily activity if applications monitor user behavior over a longer period. Second, it is recommended to create awareness of individual activity by highlighting past and current activity levels, and by providing feedback regarding goal achievement. Third, the authors underline the importance of social influence for long-term user engagement, particularly social pressure that can be increased by sharing users' levels of activity, and social support that can be achieved through the connection of users. Finally, accounting for users' lifestyles and adapting applications to individual user needs is recommended to facilitate the integration of activity-motivating technologies in daily life.

A number of authors have compiled design recommendations particularly focusing on the creation of exertion games, partially elaborating on the guidelines provided by Consolvo et al. [2006]. Campbell et al. [2008] provide six design guidelines based on theoretical game design considerations, focusing on the design of appropriate game mechanics and social aspects of exertion play. Väätänen and Leikas [2009] suggest four design guidelines that primarily address interaction and interface design. However, the authors do not elaborate on these guidelines in terms of game design. In a similar fashion, Thin and Poole [2010] examine commercially available exertion games and provide high-level guidelines for the creation of games implementing physical activity without providing explicit design recommendations. Yim and Graham [2007] present a set of guidelines for the creation of exertion games — including more detailed design recommendations addressing aspects beyond interaction design. They base their guidelines on the examination of literature investigating exercise motivation, and illustrate each recommendation using different games as well as game mechanics as an example. Based on an analysis of these approaches, we identified five core areas that need to be considered when creating exertion games, and present an overview of additional recommendations that were made by these authors.

6.1.1 Providing an easy entry into play

In order to lower the barrier of using exertion games, it is recommended to offer players an easy entry into play. Of course any game benefits from an easy entry point, however, due to the physical effort involved, exertion games require specific attention here: for example, playing might require participants to change into sports gear, conduct warm-up exercises or travel to the nearest sports ground; these are all aspects that can become hurdles for players that designers need to consider. Prior research proposed that in order to provide an easy entry into play, it is important to create an accessible user interface that is based on easy-to-use and intuitive interaction methods [Väätänen and Leikas, 2009]. Furthermore, providing tips can support an easy entry along with advice to new players and providing coaching mechanisms that facilitate gesture learning and the development of motor skills [Thin and Poole, 2010]. Apart from that, exertion games should provide easy-to-learn core mechanics to engage players without extensive learning periods [Campbell et al., 2008]. Yim and Graham [2007] summarize these considerations by stating that exertion games have to facilitate leadership for novice players, suggesting that exertion games need to provide easy-to-understand structures and game mechanics that can be picked up during play. In addition to that, they recommend the implementation of mechanisms that allow veteran players or non-player characters to guide users who have just joined the game.

6.1.2 Implementing achievable short-term challenges to foster long-term motivation

In order to keep players engaged over a longer period of time, many guidelines comment on the inclusion of achievable short-term goals in order to foster long-term motivation. Again, the same applies for any game, however, due to the long-term benefits of repeated exercise, the consideration of short-term- challenges to foster long-term motivation is particularly pertinent with exertion game design. For example, Thin and Poole [2010] note that it is important to set long-term goals. To help players achieve meta-objectives such as maintaining certain work-out routines over a longer period of time, improving their level of fitness or achieving weight loss, the implementation of microgoals to provide players with short-term gratification may support the achievement of macrogoals that might be too far in the future and could therefore be demotivating and overwhelming for some players [Campbell et al., 2008]. Yim and Graham [2007] refer to the concept of self-efficacy — an individual's belief of their ability to control events in their lives, in particular their health habits — to underline the importance of achievable goals. In order to motivate players with low self-efficacy to continuously participate in exertion gaming, they state that it is important to offer short-term goals that reward players quickly and increase their feeling of immediate achievement. As an example, they name quest structures in role-playing games, which vary between easy tasks that can be accomplished after a short time and more advanced quests that have to be followed over a longer period of time.

6.1.3 Offering adequate challenges that match individual skill levels

Offering in-game challenges to match players' individual skill levels is one of the most important aspects of exertion game design. Again, providing adequate challenges is also important for games in general, however, if a player is faced with a too-challenging hurdle in an exertion game, she/he will quickly become exhausted or even injured. Campbell et al. [2008] recommend the inclusion of "marginal" challenge to address this issue. To create a fun player experience, they point out that it is important to provide the player with challenging, yet achievable in-game tasks, which requires an accurate assessment of the player's abilities and the adaptation of game mechanics in order to accommodate different levels of player ability. Sinclair et al. [2009] introduce a dual flow model to address this issue. Based on one of the main concepts within flow theory — that an optimal experience is achieved if task challenge and individual ability match — the authors suggest that exertion games have to balance player skill and in-game challenges as well as player fitness and workout intensity to create a positive player experience. Thin and Poole [2010] suggest monitoring players' exercise efforts and adjusting game challenge based on this information to accomplish this goal. This is supported by Yim and Graham's considerations regarding balancing mechanisms for multiplayer exertion games

Yim and Graham [2007]. They recommend considering additional information such as individual target heart rates to balance efforts of novice and veteran players, allowing players of different fitness levels to compete against each other while keeping the competition challenging and interesting for all participants. Campbell et al. [2008] support this idea by recommending designing for fair play, which gives all participants an equal chance of winning through skill matching and skill balancing between players, and research by Gerling et al. [2014] demonstrates how balancing can be applied to facilitate competition between players with fundamentally different physical abilities. Similarly, Altimira et al. provide insights into balancing exertion game experiences [Altimira et al., 2013, 2014]. To explore the issue of balancing exertion experiences, Mueller et al. [2012] conducted an evaluation of the augmented sports application Jogging over a Distance [Mueller et al., 2010b,c]. Based on the results, they provide a list of design tactics. To balance players, they recommend facilitating empathy by creating awareness of other players' workout intensities and allowing players to negotiate the duration of physical activity. Furthermore, they point to supporting different levels of intensity as a design opportunity to balance exertion efforts through system design.

6.1.4 Providing users with appropriate feedback on their exercise efforts

To give players the opportunity of reviewing their exercise efforts, it is suggested to provide players with feedback on in-game achievements; for example, through progress charts that can be accessed after play or in-game feedback that informs players about their current performance [Thin and Poole, 2010]. In-game feedback offers opportunities to change bodily behavior, but might distract from the activity, whereas feedback after the game might be forgotten and harder to turn into action for the next game. Works from sports science [for example, Schmidt and Wrisberg, 2004] around the timing of feedback might be useful for exertion game designers in this regard.

Moreover, it has also been pointed out that feedback needs to be adequate in order to maintain player motivation, and that reports on overall performance should only be offered if this feature is desired by players [Väätänen and Leikas, 2009]. Likewise, it is recommended to hide players' fitness levels in multiplayer environments in order to avoid direct competition between players, which might discourage novice users or players with lower fitness levels [Yim and Graham, 2007].

6.1.5 Supporting social play to foster interaction and increase exercise motivation

Supporting social play and fostering interaction between players appears to be a core component when trying to increase long-term exercise motivation. Yim and Graham [2007] discuss this from two perspectives. First, they claim that exertion games need to avoid barriers that keep players from grouping, for example, offering different servers based on player location that are not connected or keeping players from participating in games that do not match their skill level. Instead, they suggest the implementation of an accessible and comprehensive game environment that balances competition between players to allow user collaboration across skill levels and geographic location. Second, they highlight the importance of supporting players when trying to create new groups to enable peer support. To achieve this goal, exertion games should offer mechanisms that facilitate interaction between players, for example, by supporting users in finding other people exercising at their skill level. In this context, Campbell et al. [2008] distinguish between internal and external social relations that have to be accommodated by exertion games. According to their guidelines on social play, it is important to design games that provide structures for social experiences by offering clear player roles; these internal social relations can then be utilized to foster the creation of external social relations, that is, relationships between players that extend beyond game structures. Motivated by the importance of social interaction for player motivation and possible benefits regarding the achievement of long-term goals, Mueller et al. [2009b, 2010a] provide a detailed analysis of social interaction in exertion games, and offer additional design recommendations for social play. Based on an analysis of different multiplayer exertion games, they provide six design recommendations focusing on the creation of a meaningful gaming experience for players in remote locations. Among other considerations, they highlight the importance of meta-gaming between exertion game sessions to allow players to communicate with their peers and foster social bonding, considering player movements in remote locations to account for spatial differences and considering implications of physical interaction, for example, a certain degree of uncertainty in player movements. In addition to that, they recommend the implementation of flexible game structures to allow players to reshape social gaming experiences according to individual needs.

7

Opportunities and Challenges

In this section, we highlight the key opportunities and challenges when it comes to considering exertion in human–computer interactions based on our review of the literature, but also from our craft knowledge of having designed and developed exertion games over the years. The following list is not meant to be an exhaustive nor is it presented in a particular order, however, the following opportunities and challenges appear to be prominent when it comes to designers currently considering exertion in game design, derived from related work and our own practice as well as our teaching of emerging exertion designers. Furthermore, we note that many challenges that designers initially might see as hindrances could be framed as opportunities to facilitate novel experiences designers might want to deliberately design for.

7.1 Exertion affords performative play

As exertion games invite gross-motor movement, the movement players exhibit are widely seen by others, and as such, playing in front of others affords more performative play. For example, Reeves et al. [2005] describe how the players' movements in Dance Dance Revolution are highly visible to any bystanders and how the "effects" of their movements (often visual effects and sound) can also be made available to spectators, further drawing people into the "spectacle" of the game. These performative actions can be divided into two key categories: Primary performances that contribute directly to the game's outcome (such as hitting a serve in Wii tennis) and secondary performances that do not directly contribute to the outcome of the game (such as a pumping fist after an ace). These secondary performances are particularly important in exertion games when compared to traditional button-press games: As the primary performance focus is already on the body, any secondary performance can build on this. For example, any visual focus of a button-press game is mostly directed at the screen, whereas a secondary performance will require a redirection of this visual focus. Furthermore, players who want to perform such secondary performances will need to remove their hands from the gamepad. Therefore, exertion games afford the support of secondary performances more than button-press games.

Of course secondary performances could also appear on the screen, for example, in a button-press game a player could instruct its avatar to perform a pumping fist celebration through a dedicated button command. However, executing such secondary performances depend on which ones the game designer enabled, and also require the cognitive processing of an emotional expression into a learned button command.

This performative character of exertion interactions supports social play [Bianchi-Berthouze, 2013, Lindley et al., 2008]. By social play we mean "active engagement with a game (through use of its controls or through observation and attention to ongoing gameplay) by more than one person at once" [Isbister, 2010]. In particular, Bianchi-Berthouze showed that players who used a controller that afforded movement (in contrast to a button-controller) had a social play experience with increased degree of social interaction [Bianchi-Berthouze, 2013]. The author postulates that as the controller invites movement, enabling empathetic gestures to express emotions, it allowed players to become more emotionally involved. The author believes that the positive affect in turn facilitated social play, as it is known from evolutionary psychology that positive mood can facilitate social interaction [Haviland-Jones et al., 2005]. Similarly, another study showed that people investing physical effort as part of a game reported a greater sense of connectedness than players who used a keyboard interface [Mueller et al., 2003].

It is important to note that research also showed that players value the heightened social play experience that exertion games afford [Voida and Greenberg, 2009]. Similarly, a survey on the effects of playing Dance Dance Revolution highlighted that players appreciated the social benefits resulting from playing the game [Hoysniemi, 2006].

However, the rise of exertion games that run on mobile phones suggests that a key advantage of these games is that they can be played anywhere, and using the private nature of mobile phones screens, without disturbing others. For example, many people enjoy mobile games during waiting periods such as on public transport. Games have been developed to introduce exertion into these gaming activities, for example see Cart-Load-O-Fun [Toprak et al., 2013]. However, engaging with exertion games during such periods raises issues of social acceptance: A keynote by [Vandeen Abele, 2013] showed some acted scenarios of performing physical activity in non-sports public settings, highlighting how this can be associated with a social stigma of performing awkward bodily actions in public. The work by Goffman is relevant here as it reminds us of the importance of how people want to present themselves and want to be perceived [Goffman, 1959]. For exertion games, this means that designers always need to think about the social perception that the performative actions afford in public settings.

In summary, exertion affords more performative play. Interestingly, by affording performative play, exertion games also invite more social play, which in turn is appreciated by players, however, this performative play can raise issues of social acceptance.

7.2 Exertion affords affective play

With the introduction of the Nintendo Wii, an article by Lehrer proposed that Wii's real innovation is not that the motion-based controllers are making game play more intuitive (as claimed by Nintendo), but rather that they make video games more "emotional" [Lehrer, 2006]. The author leans on Damasio's [1999] statement that "the mind is embodied, not just embrained" to argue that the "body loop" — in which the brain and body are constantly interacting with each other — explains how if Wii games are able to "excite the flesh, the emotions are not far behind" [Lehrer, 2006]. The author's conclusion is that, in contrast to, for example, Sony Playstation games with their superior visual realism, the Wii games end up "*feeling* [italics in original] much more realistic" [Lehrer, 2006]. However, such physiological activation can also amplify negative game experiences, for example, "dying" might lead to greater grief in an exertion game compared to a button-press game, or a not-well designed exertion game might result in greater frustration for players.

In recent years research projects have emerged that investigated the relationship between exertion in games and affect experiences. Bianchi-Berthouze found that players can transition from a mostly attention-based and "hard fun" [Lazzaro, 2004] experience to a more affective experience [Bianchi-Berthouze, 2013]. Players who engaged in movement during game play exhibited a significantly higher number of positive emotional expressions and higher arousal. The players were showing not only simply frustration or expressions of personal triumph but also expressions of general enjoyment. The author proposed that these positive expressions could be due to the somato-sensory feedback derived from the movements. The author argues that as their game offered players to play a particular role through the movements, the player was led to experience emotions that were related to the experience of the role: For example, by entering a "fantasy role, a broader emotional experience can take place" [Bianchi-Berthouze, 2013]. Interestingly, players seem to appreciate this affective experience to the extent that they perform these movements even if this interfers with the game performance. However, it was also found that the movements needed to be well designed: only if the movements were role-related and unique to the game scenario a resulting affective experience was observed.

7.3 Exertion affords "easy fun"

Prior research highlighted how one of the key reasons why people play computer games is because of the "fun," in particular, there is "hard fun" and "easy fun" [Lazzaro, 2004]. "Hard fun" refers to the enjoyment that comes from overcoming challenging obstacles, such as when figuring out a particular hard puzzle, resulting in emotions like the delight of having overcome a difficult challenge. "Easy fun," on the other hand, refers to the sheer enjoyment of experiencing the game activities, in which the player's attention is captured through the sensation of wonder, awe, and mystery [Lazzaro, 2004]. A typical example is the enjoyment that comes from exploring a beautiful virtual world. Research has shown that body movements in games can facilitate such easy fun [Bianchi-Berthouze, 2013]: The author found that if the game promoted movement, the number of role-related movements was significantly higher and players also reported higher levels of engagement. Hence movements that relate to the role of the players may help players in entering the fantasy world of the game. The author states: "The mechanism that facilitates the shift from hard fun to easy fun could be the proprioceptive system that provides sensory motor feedback from the body configuration and movement" [Bianchi-Berthouze, 2013]. The important message here is that the quality of engagement changes from hard fun to easy fun as the players enter a loop in which the more they move, the more they are affected and the more they want to move.

We believe one source of easy fun can be the joy of movement: research has argued that exertion games support the joy of movement, proposing that the main source of enjoyment comes from bodily engagement [Segura et al., 2013]. Moving can be inherently enjoyable. Research has highlighted how people can find movement incredibly joyful, and in particular dance research has contributed to knowledge on how interactive technology can be used to support this joy of movement [Loke and Robertson, 2010, 2013, Moen, 2006, Schiphorst, 2007], an area exertion games can learn from. This is especially relevant as it has been argued that by supporting the joy of movement, exertion games can support the intrinsic motivation that comes from being able to move, rather than just supporting extrinsic rewards [Segura et al., 2013].

7.4 Exertion affords physical health

An obvious strength of exertion games is that they can facilitate physical activity and as a result physical health. Research has shown that playing an exertion game can consume more energy expenditure than playing the same game using button controllers [Graf et al., 2009, Graves et al., 2008, 2007, Lanningham-Foster et al., 2006]. As such, it is believed exertion games can contribute to a healthier lifestyle (as it is assumed that more movement means improvement over a sedentary lifestyle) in contrast to non-exertion games [Graf et al., 2009]. On the other hand, exertion games have also been criticized for not facilitating the same energy expenditure as their traditional sports counterpart [Graves et al., 2008], possibly due to the limited movement opportunities afforded by the living rooms in which the games in these studies were played. Overall, there seems reasonable evidence that suggests that exertion games can facilitate more energy expenditure than button-press games, however, most popular exertion games played with game consoles fall short when it comes to the exertion intensity of traditional sports activities. Emergent research areas such as augmented sports (discussed earlier) may provide insights into closing this gap.

7.5 Exertion affords time-constrained engagement

Traditional button-press games are known for being able to engage players uninterrupted for many hours on end [Griffiths and Meredith, 2009]. In contrast, exertion games can only engage players uninterrupted for a shorter period because players get tired and cannot sustain to play at high intensity levels for too long. As such, exertion affords time-constrained engagement that designers, especially those coming from a button-press game background, need to consider.

7.6 Exertion and sustained engagement

Exertion games have been criticized for falling short of sustained engagement, in particular, the arguments come from observing people's use of home consoles such as the Wii and how people stopped playing them after a while. We agree that exertion games can be better designed to promote more sustained engagement, and research efforts into this area have emerged [Voida et al., 2010, Voida and Greenberg, 2009]. However, we also want to point out that maybe our expectations towards exertion games come from our understanding and familiarity with sports that can engage people for a lifetime. Yet maybe exertion games do not need to be (and maybe should not be) like sports, but should rather facilitate a new type of physical activity experience. For example, exertion games can be designed to be easier to begin with than a sport (for example, see how much easier it is to play the first game of tennis in Wii Sports compared to traditional tennis), and exertion games have the opportunity to offer a great variety of game experiences with little extra physical material (for example, see the opportunity Kinect players have to play many games just by downloading a different game). As such, exertion games should potentially be looked at more from our understanding of computer games (with many titles not played for a long period, but instead the variety of available games facilitates sustained engagement) rather than our understanding of sports' ability for sustained engagement.

7.7 Exertion and physical impairment

Button-press games have been applauded for their low entry barrier, and in particular people with physical impairments have been using online computer games as a means of social engagement, as their physical impairments are not visible to other players. In contrast, most exertion games require a certain fitness level or at least deal in a limited way with physical impairments. Research has identified this and tried to address some of these issues [Hernandez et al., 2014, Morelli et al., 2010], however, this is early days and most commercial systems are still designed only for a non-impaired player in mind [Powers et al., 2015]. Some of these challenges can stem from limitations of the underlying sensing technology, for example, the Kinect camera does not recognize people in wheelchairs well; other challenges are how to design gameplay to accommodate players of different physical abilities [Gerling et al., 2014]. In summary, most exertion games pose certain barriers for players with physical impairments due to their bodily focus in a way most button-press games do not, limiting the expansion of the field.

7.8 Exertion and technology setup

As most exertion games use some sort of sensing technology, players are often required to either go through some calibration procedure, set up the environment to accommodate sensor limitations, or put on sensors themselves. For example, the Kinect works best in certain lighting conditions and with little furniture behind the player, while the Wii and Nike+ systems require players to carry a Wiimote or mobile phone. Besides the inconvenience of wearing these sensors, we also highlight that setting up and preparing the operation of these systems adds to the preparation time required for engaging in physical activity (such as changing into sports gear). This is time deducted from the time players can engage with the game, possibly limiting opportunities for sustained engagement.

8

Research Directions

As exertion games is an emerging and evolving field of research, there are many unanswered questions and research opportunities still lying ahead. The next section therefore highlights a set of key research directions we believe to be salient in the next years of future exertion games research.

8.1 Long-term in-the-wild studies

Exertion games is a relatively young field, hence most studies of their use tended to be conducted in laboratories, where players were exposed to the game for the period of time the laboratory was available. If studies were conducted "in-the-wild" [Rogers, 2011], such as in people's homes, they were often rather short exposures. This is understandable, as these studies often involve fragile or expensive technology that works best under certain, controlled conditions with technical support readily available. However, with advancements in technology, longer in-the-wild studies are possible that might answer some of the remaining questions, in particular:

- Is the game engaging over a longer period of time? Although not all games need to be engaging for long periods and the same applies to exertion games (for example, see the trend around casual exertion games that are only played for very short periods at a time [Gao and Mandryk, 2012, Sra and Schmandt, 2015]), long-term studies can give us insights into which games are engaging over long periods and which ones are not, contributing to our knowledge on long-term engagement effects.

- Do those exertion games that promise health benefits provide them over the long term? For example, do weight-loss games lead to sustained weight loss?

- Does kinesthetic learning occur and how? Understanding this will allow for more knowledge on how to utilize technology to support training and bodily learning.

- How are users appropriating these games? For example, users have previously used exertion entertainment systems for their health games: the Wii was not aimed at facilitating weight loss initially, however, users quickly appropriated it for their weight loss agenda [DeLorenzo, 2007].

Two examples of research projects that did employ long-term in-the-wild deployments are the work investigating long-term use of motion-based games in care home settings [Gerling et al., 2015] and the work investigating Liberi — a bike-based game system to support children with cerebral palsy to exercise together through networked social play [Hernandez et al., 2014]. The former was evaluated over a series of 3 months and focused on player retention and issues related to the context of playing games in care-homes, while the latter was evaluated over a series of 10 weeks and focused on the social interaction that resulted. In a separate 6-week study of the system, the researchers also focused on motor improvements, cardiovascular fitness, exercise tolerance, and health-related quality of life questions [Knights et al., 2014]. Both of these research projects required significant overhead and larger teams of researchers to collect the desired data.

Future evaluation studies might require a reconsideration of any methods, for example, remote data logging, supplemented with data from additional sensors (like scales that connect wirelessly to the game to monitor weight loss) might become more important especially with an increase in the number of participants.

8.2 Actuation

Many exertion games feature a coupling between the physical and digital world, however, this coupling can often be lopsided [Koleva et al., 2000], that is, the physical world has an immediate effect on the digital world, but not the other way around. For example, in many exertion games, the players' bodies directly affect virtual game elements, however, the virtual game elements rarely directly affect the players' bodies. One key way to achieve this is through the use of actuators that can directly affect the players' bodies, enabled through technology that provides force-feedback.

Force-feedback has been around for a while; however, advances around actuation technology that can directly affect the body does not seem to advance at the same pace as technology that senses exertion: Technologies can now sense extreme exertion actions, including high impact and high speed bodily actions often exhibited in extreme exertion activities (see, for example, the work supporting martial art boxing [Chi et al., 2004, Mueller et al., 2014a]), that was difficult to sense not so long ago. In contrast, actuation technology is often not very fast and not very powerful. Furthermore, actuation technology is often limited to very specific actions, for example, applying force only along one direction. This contrasts with the wide range of bodily actions human players can exhibit. Even if more advanced actuation systems exist, they are often expensive and cumbersome to operate. With more advances in the field of actuation technology and associated force-feedback experiences, we believe the field of exertion games can benefit.

8.3 Exerting machines

A particularly future-oriented research direction is the area of exerting machines. From sports research we know that exercising with others, even if this occurs in parallel, that is, there is no bodily interference, participants' pain thresholds change so that participants can work out harder and for longer [Cohen et al., 2010]. In other words, if exertion is involved, the presence of other people also exerting can result in physiological responses from the body that affect the exertion experience in return. This phenomenon has led to the research direction that investigates if independent interactive systems can facilitate similar effects, that is, the research explores if there is a benefit when interactive systems also exhibit physical effort as part of the interaction. For example, work on a flying quadcopter as a jogging companion [Mueller and Muirhead, 2015] showed that the physical effort from the machine could offer benefits to the exertion activity: The authors proposed that the physical effort the quadcopter invests (by flying, which requires significant battery power and mechanical movement of the propellers) could be a beneficial match to the physical effort investment of the jogger, resulting in an enhanced bonding experience between two effort-investing systems — the quadcopter and the jogger.

8.4 Exertion interactions beyond the screen

Many exertion games feature some kind of display, often a computer monitor, TV, or mobile screen. Screens are great in stimulating the visual senses and have served the history of digital games well. However, the heightened focus on the body in exertion games requires a rethinking of the screen-dominance: Screens can focus the interaction, and as such, draw the players' attention towards the screen. This can weaken the visual attention directed elsewhere. This omnidirectional focus on the screen has allowed players to immerse themselves into games and associated worlds, but on the other hand it has also made players often forget everything else around them [Salen and Zimmerman, 2003b]. With a heightened focus on the active body, exertion games can benefit from drawing visual attention on the body. For example, the active human body can be a "spectacle" that can contribute to an engaging experience [Khot et al., 2015]; as such, game designers might want to draw players' (and observers') visual attention to the body. Furthermore, players can benefit from paying attention to their own body, supporting their proprioceptive sense. Furthermore, designers also need to think about safety aspects, for example, when players are moving through urban environments as part of an exertion game experience [Benford et al., 2006], a screen that focuses the interaction diminishes the visual attention that can be directed at the urban traffic. As such, we believe an important future direction for exertion games is the understanding of the advantages and shortcomings of screen interactions. Several examples that investigated this have already emerged: there are exertion games that use traditional console equipment, but show no visuals on the screen to facilitate social engagement [Fabrik, 2014], there are exertion games that focus on audio-only output [Mueller et al., 2010b], and there are exertion games that utilize haptic feedback to the extent that they can be played by blind people [Mueller et al., 2010b]. These games highlight how a focus away from the screen can direct attention to the body, and in exertion games, this is "where the action is" [Dourish, 2001].

8.5 Indirect input techniques

In many games, players have to execute actions that contribute directly to the game (such as moving the avatar toward its goal) and other actions that are only indirectly contributing to the game (such as selecting the avatar that the player wants to control). Often, these direct and indirect actions are separated over time; for example, the player selects his/her avatar as part of a menu selection, separate from "core" gameplay, and then gameplay starts and direct actions are required. However, direct and indirect actions are not always separated temporally, sometimes the player might want to (or needs to) execute an indirect action during gameplay. Today's game controllers support this especially, offering the execution of indirect actions through dedicated "secondary" buttons (such as the "go back to main screen" or "pause" button). However, in exertion games, the body is often occupied with direct actions, where interrupting the player to execute indirect actions is not feasible. For example, in a game where the direct action is to do a handstand, interrupting this to execute a menu selection action seems unreasonable. Therefore, finding new techniques to support indirect game input, for example, through the use of eye-tracking that triggers indirect actions, is an interesting research direction for future work on exertion games.

8.6 Supporting outdoor interactions

Most current exertion games technologies work best when used indoors, where lighting, temperature, and other environmental factors can be controlled. For example, when sensing movement with cameras, sunshine hitting the cameras can often lead to detection problems. However, many exertion activities occur outdoors, where weather conditions and other environmental factors can often significantly influence the exertion experience. First, environmental conditions can affect the bodily exertion, and it might be beneficial if the technology knows about this — for example, a system might detect that it is very hot outside and therefore adjust the intensity level for the day. Second, if technology is used outdoors, it needs to withstand the outdoor conditions associated with it — for example, technology to support surfing games will need to withstand the oceanic environment, technology for climbers will need to withstand different altitudes, and games in deserts will need to deal with soaring temperatures. Advances that can deal and consider the unpredictable environmental challenges that come with outdoor use are therefore a key area for future work.

8.7 Contribution to wellbeing

Another key research direction is to understand the contribution that exertion games can make to support the growing area of wellbeing and wellness. Wellbeing as a research field is relatively new, and as such, there is not much investigation so far on how exertion games can (and should) contribute to the field of mental and emotional wellbeing. For example, a few projects have emerged that aim to make a contribution towards understanding the potential of technology augmentation in a playful way to areas such as yoga [Nagargoje et al., 2012]; however, these systems suggest to us that this area is still in its infancy. We believe exertion games can make a significant contribution to the wellbeing space and encourage researchers to take up the challenge and investigate this further.

8.8 Bodily poetics

Prior research in arts suggests that involving bodily movement in interactive experiences comes with a certain bodily poetics [Wilde, 2011]. Some of this research originated from tangible interaction research, where early investigations highlighted that not just the design of the form of the tangible object can benefit from a poetic perspective, but also the design of the movement [Shaer and Hornecker, 2010]: The authors propose that designing a poetic aesthetic to movement is one key future research direction, and we extend this direction to the design of exertion games. We believe exertion games can both benefit from a view on bodily poetics and also contribute to an understanding of it; however, how this can be achieved is still relatively unexplored. A further understanding of bodily poetics will help identify the role that exertion games can bring to and draw from this area.

9

Conclusion

Exertion games comprise a growing field of research with wide applications that draw from previous investigations across interaction design, play, sports, health, and entertainment domains. The field includes many challenging problems, widening our view on the role of technology in people's lives. However, the field also has potential to offer positive impacts. The field is interdisciplinary, hence researchers need to understand their work in a broader context.

This article began by presenting the various definitions of exertion games that exist in the field before presenting typical examples that can be laid out across a spectrum that highlights how many approaches come from either a game design background or from a perspective of augmented sports, with the in-between examples depicting an interesting area where a lot of innovation potential exist, offering novel exertion play experiences. We then articulated fundamental issues using the exertion framework, which allowed us to structure implementation approaches that then in turn highlighted technical challenges that are yet to be resolved. We then summarized theoretical approaches that are relevant to exertion game designers in order to articulate opportunities as well as open research directions that the field could benefit from considering. In summary, this article has aimed to present the various aspects to consider when designing exertion games, identify key opportunities while discussing significant challenges that are likely to shape the field in the future. Ultimately, with our work, we hope to help the field to grow in order for more people to profit from the many benefits associated with exertion.

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