Designing for Bodily Interplay in Social Exertion Games

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While exertion games facilitate, and benefit from, social play, most exertion games merely support players acting independently. To help designers explore the richness of social play in exertion games, we present the design dimension "bodily interplay" that gives critical focus to how players' bodies interact with one another. We offer two broad categories of bodily interplay—*parallel* and *interdependent play*—to explain how exertion games can facilitate independent and offensive/defensive-type experiences. These categories can be applied to both the physical and virtual space, and by looking at all permutations of these categories, we articulate four ways of coupling the spaces: comparative, actuated, derived, and projected coupling. This article illustrates the inspirational power of the dimensions by applying them to the analysis of four exertion games. Altogether, we articulate a vocabulary that can guide designers in the creation of social exertion games, helping players profit from the many benefits of exertion.

CCS Concepts: • **Human-centered computing → Interaction paradigms**

Additional Key Words and Phrases: Exertion games, exergame, movement-based interaction, whole-body interaction, bodily play, bodily interaction, social play, sports

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1. SOCIAL EXERTION GAMES

There is a growing trend toward digital games that require bodily investment, where the whole-body interactions contribute to the outcome of the game. We call these *exertion games* [Mueller et al. 2003]. Probably, the first exertion game to achieve a high level of success was "Dance Dance Revolution" [Behrenshausen 2007]. Today, many game consoles support exertion game experiences through the Kinect [Microsoft 2010], Wii, and Move [Sony 2010] sensing systems.

Exertion games have been applauded for their potential to provide health benefits [Graves et al. 2007; Lanningham-Foster et al. 2006; Maddison et al. 2007] and to support novel and engaging experiences [Fernaeus 2012]. Our focus, however, is on research developments that suggest that exertion lends itself to social play [Juul 2009; Lindley et al. 2008; Mueller et al. 2003; Strömberg et al. 2002; Wakkary et al. 2008]. Borrowing from Isbister's definition [2010], *social play* is for us the active engagement

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with a game by more than one person. We focus on people who engage directly with the game through its controls, i.e., we leave audience participation out for now. Understanding social play is important. In contrast to solo play, social play can provide more positive experiences, less tension, and greater competence [Gajadhar et al. 2008] as well as less frustration [Mandryk et al. 2006]. Furthermore, many gamers already play with others [Brand et al. 2014; Entertainment 2015]. In consequence, in this article we respond to the call that in order to thoroughly understand games, we must include investigations into the social nature of the experience [Isbister 2010].

The exertion games mentioned earlier support social play: Dance Dance Revolution is a two-player experience, the Kinect 1 was designed with up to four (Kinect 2 with up to six) players in mind, and Nintendo Wii and Sony's PlayStation Move is sold with two controllers. While these systems support multi-player gameplay, we argue that many associated games have not yet fully embraced social play relating to exertion. We call this *social exertion play*, which occurs when there is active bodily engagement with the game through use of its controls by more than one person. Social exertion play is particularly concerned with the interplay between players' bodies, akin to many traditional sports that involve a range of bodily interactions. These include pushing, pulling, hauling each other's bodies, and strategic moves, such as feinting and countering. We note that this rich range of bodily interdependent actions we are familiar with from sports seems to be often very different to the experiences players encounter in exertion games: In most commercial exertion games, players move their bodies on their own, individually, and independent of each other, such as flailing their arms at a screen. Any bodily interplay that may occur is mostly incidental rather than integral to the gameplay experience. This is observed in Wii accidents where players strike each other accidently as a result of flailing their arms [WirHabenFun 2011]. This suggests to us that there is still undeveloped potential when it comes to supporting the wide range of social exertion play possible.

We find, however, that creating social exertion play experiences is not straightforward. For example, player experience research states that adding players to a game session creates a fundamentally different game experience [Isbister 2010]; hence, simply adding additional players is not sufficient to make the game social. Furthermore, social play in exertion games is different to social play in button-press games [Voida and Greenberg 2009]. Therefore, it has been suggested that social exertion play benefits from its own investigations [Bogost 2006, 2007; Lehrer 2006; Sheridan et al. 2005]. While interaction design is providing insights about designing for the exerting body [e.g., Bekker et al. 2010; Loke et al. 2013; Yim et al. 2007], sports science is examining exertion activity in a social context [e.g., Hagger and Chatzisarantis 2005] and traditional game design is offering an understanding of the design of social games like Facebook games [e.g., Koster 2011], there is a lack of knowledge about the combination of exertion and social play in digital games. We note that it is not enough to simply combine our knowledge on exertion games and social play, as exertion has so much more to offer social play, thanks to the involvement of the body [according to de Kort et al. 2008]. We believe there is an underexplored opportunity to support the full richness of social play; if left untapped, we fear this will constrain the full potential of exertion games.

We believe that the reason why social play in exertion games is underexplored is two-fold: First, current technologies present limitations on the bodily interactions that can be (easily) supported and as a result, constrain the opportunities for players to experience a wide range of social play interactions. Second, there is a lack of structured understanding of these bodily interactions, and subsequently there is a gap in understanding how to design for them. Both industry and research have stressed that this gap of knowledge on social play in exertion games needs closing. Industry has lamented that exertion games have not yet lived up to their expectations [MacDonald 2014] and researchers have pointed to the missed opportunities arising from exertion games not properly supporting social play, leading to unsatisfying player experiences [Bogost 2007]. Fortunately, the same authors believe that with better game design, exertion games could offer rich social play experiences and in consequence serve players better [Bogost 2007; MacDonald 2014]. As such, we find that limitations of exertion games in regards to supporting social play are often due to incomplete game design knowledge. Without a conceptual understanding of the design of social play in exertion games, (a) our knowledge of social play is incomplete; (b) designers miss out on opportunities to offer novel social game experiences; (c) players miss out on enhanced performance effects [Cohen et al. 2010] as well as motivational drivers [McElroy 2002] that result from engaging in exertion together; and (d) players have a limited amount of social play experiences available to them, constraining opportunities to fully engage and as such, players will not profit from the many physical and social benefits these games offer.

To address this gap in knowledge, this article proposes an initial understanding of designing social exertion play. We offer support to designers of future games by providing them with guidance on how to consider players' bodily interactions and how to support these interactions with technology. We believe that designers of current exertion games will benefit from this guidance, which highlights current constraints and reveals the hidden design assumptions of the form these games should take. We hope that designers of current button-press games intending to venture into exertion games will also benefit from our work as it provides them with the opportunity to incorporate a structured understanding of social exertion play into their designs.

We acknowledge that bodily aspects are not the only elements relevant to social play in exertion games; for example, we know from sports that other aspects like yelling and cheering can also have an effect on the sociability of the game. Nonetheless, as exertion games feature bodily action, and are therefore in stark contrast to a history of digital games that largely ignored bodily aspects, we believe it is time to take a body-centric perspective and examine the interactions between players' bodies to enhance our knowledge of social exertion play. We posit that this knowledge contributes toward a more comprehensive understanding of social play.

The orientation of our work is summarized in Figure 1. Knowledge exists about social games and social exertion as well as exertion games; however, little understanding is available about the intersection between the three: social, exertion, and games. Our work contributes toward building this interconnected understanding.

We begin by discussing related work. We then present "bodily interplay" as a conceptual dimension that has two key categories: "parallel play" and "interdependent play." By introducing two instantiations of the bodily interplay dimension, bodily interplay in the physical and in the virtual space of play, we are able to present a two-dimensional design space of social exertion games. This design space helps uncover four broad design strategies to design social exertion games in terms of the coupling between bodies and their representations. To demonstrate the utility of our framework, we apply it to the design of four social exertion games, with three of them stemming from our own game design practice. Finally, we offer concluding remarks where we propose that our approach can help designers identify opportunities for supporting social exertion play and ultimately help more people profit from the many benefits these games offer.

2. BUILDING ON PREVIOUS INVESTIGATIONS INTO THE DESIGN OF SOCIAL EXERTION PLAY

There are two broad approaches that researchers and practitioners have previously used to investigate the design of social exertion games. From a theoretical perspective,

Fig. 1. Our focus.

researchers have examined what role our exerting bodies play in our interactions with technology. From a systems development perspective, researchers have digitally augmented social play as well as exertion interactions. Furthermore, research has also examined various ways of representing users' bodies in virtual spaces. We now describe some of the key works and articulate how they have informed our thinking.

2.1. Understanding Social Exertion Play Through Theory and Conceptual Frameworks

Our focus on social exertion games is largely stimulated by research in interaction design that considers how bodies interact with one another, often situated under the notion of movement-based interaction [for example, see England et al. 2009; Fogtmann et al. 2008; Larssen et al. 2004; Loke et al. 2007; Moen 2006]. A number of frameworks have emerged out of these prior investigations: Eriksson et al. [2007] presented a framework to describe the various positions of the body and its limbs when users are moving around interactive installations. This framework focused on camera-based interactions and therefore scenarios where users occupy a pre-defined space; as such, it provides an understanding of the different ways technology can deal with users moving around a space (this is considered in our framework under Section 3.4.5.). Although the work considers multiple users, it does not consider if and how people move in relation to one another. Furthermore, it does not consider body-contact cases where participants might bump into one another (for example, when distracted by projections on the floor), apart from highlighting that camera-based systems might have difficulty sensing such interactions. Our work builds on this by explicitly considering such body contact while expanding technology considerations beyond camera-based systems.

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 inspired parts of our work, in particular the notion of "shared objects" that made it into our framework; however, their work does not focus on the interdependency between users' bodies and tangible objects, which our work explicitly considers.

Similarly concerned with the interplay between bodies and tangible objects, Benford et al. [2005] presented the "expected, sensed, and desired" framework to support the design of ubiquitous computing systems. The framework's technological orientation aligns with the design focus of our work (i.e., we are also using a framework to highlight development opportunities that exist for technology designers); however, the expected, sensed, and desired framework falls short when it comes to considering any interdependencies between exerting users, which our work adds.

Loke et al. [2013] developed a methodology to support working with the moving body and the kinesthetic sense, originating from dance and movement improvisation. The authors focus on the relationship between the computer, the moving user, and the audience. We are fascinated by the emphasis placed on the social interactions between bodies by Loke et al.; however, we look more generally at interactions between exertion bodies and not just between bodies of dancers and audiences.

Hummels et al. [2007] developed a structured approach to designing for what they call moving bodies. They conceptualize bodily movement as a design material and give practical advice on how designers can develop bodily movement skills. The analysis offers an interesting contrast to, for example, studies that focus on bodily interactions with technology that might incidentally (rather than intentionally) lead to body contact.

Another framework that inspired us is Hall's [1969] work on interpersonal distance between people, which explains how interpersonal distance affects interactions. This has contributed to the "proxemics play framework," which highlights how the physical distance between players' bodies can be a resource for game design [Mueller et al. 2014]. Proxemics has helped us to categorize the distances between players by identifying key distance thresholds. Our work extends this framework by contributing an understanding of the different *ways* bodily interplay can emerge between players across the different distance thresholds.

Segura et al. [2013] presented a "design space for body games," highlighting the technological, physical, and social issues that arise during the design process of such games. By shifting the focus from movement as interaction technique to the social experience of the players in the game, their work shows how the social and physical settings become important design resources. We applaud this shift toward the social experience. However, their research was primarily derived from a device that was meant to be used originally by a single player. Their focus is on social interactions where one player is interacting with a device while others are watching; hence, the work is limited when it comes to an understanding of the bodily interplay between players.

Moen [2006] advocated considering the pleasure that arises when players are exerting. Her work also originated from a dance perspective and consequently the analysis is derived primarily from a single-user device perspective. We seek to complement her understanding by articulating a set of ways users can experience bodily relationships with each other and across devices.

Focusing on how multiple people interact with an exertion game, Larssen et al. [2004] studied two Eyetoy games in order to understand exertion as input for interaction. Their games used a camera that works best with independent gameplay. Despite the technological advances in exertion games since this study was published, we consider these camera-based games, and aim to provide an updated and comprehensive picture of how players and their bodies can interact with one another.

In summary, we find that when it comes to social exertion play and theory, many existing frameworks consider people's exertion during interactions with technology but tend to focus on the movement of individual users or users moving independently. Our work aims to complement this prior work by contributing understandings of the various ways players can interact with one another during exertion play, while also offering insights into how designers can explicitly support such bodily interplay.

2.2. Understanding Social Exertion Play Through System Design

Design researchers and practitioners have created systems to support social exertion play, and associated studies have led to knowledge about social exertion play that has informed our work.

In their research around handball, Ludvigsen et al. [2010] noted that it is important for designers to consider the entire range of possibilities for bodily interactions. This includes intense physical body contact that can occur during play. This is something that many interactive systems so far seemed reluctant to address [Mueller et al. 2014]. Fogtmann [2007] coined the term "kinesthetic empathy" to describe how bodily actions are affected by other people during sports activities, such as when players bump into and push each other. Kinesthetic empathy occurs when the other person's body is affected not only by their own muscle actions, but by someone else's [Fogtmann 2007; Fogtmann et al. 2008]. The authors point out that not all exertion activities are easy to categorize. There are different levels of kinesthetic empathy; hence, our formalization incorporates the diversity of these bodily interactions. Fogtmann [2007] mostly examined non-augmented bodily interactions. Our work extends the idea of kinesthetic empathy with a particular focus on the opportunities for augmentation with technology.

The game design work by Fullerton et al. [2004] and Koster [2011] found that a wide range of player interdependencies can occur in social games, and that the rules of the game can influence these social actions. From these works, we learn that digital games can support a variety of social actions, including between player representations (such as avatars). These observations are similar to the range of bodily interactions described above (as known from sports), except that here the interactions occur in the virtual space. For example, avatars (like sportspeople) can bump into each other, but they can also "walk through" each other if the software allows. Our research extends this work by articulating the opportunities but also challenges when these interactions occur both in a virtual and physical space.

Campbell et al. [2008] designed their own exertion game to investigate how an often individual activity such as jogging could become more social through the introduction of a virtual space. The authors highlight that a virtual space offers novel opportunities to support relations between participants. For example, the authors suggest that any mapping of exertion activity to a virtual space can support a balancing among players of different abilities, i.e., less-fit players can engage with fitter players, something that is more difficult to achieve in the physical space. Thus, bodily interactions across the virtual and physical space can offer unique opportunities; we consider this through our different "couplings" in Section 5.

Lindley et al. [2008] compared interactions between a movement-based controller and a conventional gamepad. They found that the bodily movement can lead to a qualitatively different form of engagement, and to design for it, they suggest examining the players' interactions in both the virtual and physical space. Following their advice, we examine exertion interactions in both the virtual and physical space of play and any coupling between them.

Voida et al. [2010] also studied how people engage with commercial exertion games. The study presented two major findings: The design of the game can significantly influence how players relate to one another; and the consideration of both the virtual and the physical space is important to understand players' experiences. In particular, the authors 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. Building on this, our work examines the interactions between players in the physical space and how the way they are represented in the virtual space affects social play.

The interplay between the virtual and the physical is also observed in the game Kick Ass Kung-Fu [Hämäläinen et al. 2005]. It requires exertion by promoting intense martial arts moves, where the avatar on the screen exaggerates any player's movements (i.e., if the player jumps, the avatar makes a massive leap). This influenced our investigations to consider the potential of alternative representations beyond simple one-to-one couplings of exertion actions, articulated in Section 5.1.3.

Human Pacman [Cheok et al. 2004] is an augmented reality (AR) version of Pacman, in which the carrying of AR equipment and running around streets "in the wild" requires exertion from its player. Although not initially designed to support multiple players, it highlights the social aspects designers need to consider, in particular when bodies are exerting amongst a world full of other bodies such as bystanders. Although accidents while playing are not reported, we can envision that during extensive gameplay with fast running around busy streets, the player's body (especially with all wearable gear extending the body's circumference) bumping into bystanders is a bodily interplay possibility that designers need to be aware of. Such exertion interactions in social spaces, where players might need to navigate around unwitting bystanders, are described through our "shared space" sub-category we articulate later.

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. These are as follows: interactive play objects can stimulate social interaction and physical play by providing motivating feedback to players' behavior; the objects can allow players to create their own game goals and rules in an open-ended play context; and the objects can support social player interaction patterns. These values can also be applied to our designs; in particular, we similarly find that different designs of interactive objects can support different social interactions (their design value no. 3). We complement this work by extending our understanding of what kind of design affords what kind of social interactions.

When it comes to research specific to social exertion games, previous work suggested that the bodily interactions occurring in social exertion games are distinct and can be categorized into discrete groups [Mueller et al. 2008]. Similarly, 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. Furthermore, Broadhead [2004] argues that there is a social play dimension, while Parten [1932] says that social play can be divided into different sequential categories. On the other hand, Koster [2011] argues against categories in social games, saying there are "various shades of grey" in social games, and that these "various shades" are a better way to look at social dynamics as they can be useful resources for design. In response, we combine the ideas of categories and "various shades": We articulate a dimension that describes a wide range of possible actions, while introducing categories along this dimension, to articulate key social experiences.

2.3. Representing Bodies in Virtual Spaces

We are also learning from CSCW (Computer-Supported Cooperative Work), as the field has already recognized the challenges of representing users' bodies in virtual spaces. Benford et al. [1995] define the associated user embodiment as "the provision of users with appropriate body images so as to represent them to others and also to themselves." The authors identify a list of embodiment challenges: "presence, location, identity, activity, availability, history of activity, viewpoint, action-point, gesture, facial expression, voluntary versus involuntary expression, degree of presence, reflecting capabilities, physical properties, active bodies, time and change, manipulating your view of others, representation across multiple media, autonomous and distributed body parts, truthfulness, and efficiency." This list highlights the extent to which researchers have already considered representations of users' bodies; however, in the reference above, the design is mostly concerned with videoconference scenarios where participants are rather inactive (compared to sports experiences). Nevertheless, our work is most closely concerned with what Benford et al. call "active bodies."

The work by Hindmarsh et al. [1998] on supporting multiple users and their bodily actions resulted in the finding that representations of actions are challenging to design when there are many things going on at the same time, a situation we can certainly relate to as we are concerned with exertion actions such as those occurring in sports. Greenhalgh et al. [1995] favor a spatial model when it comes to bodily representations. They propose the notion of aura, which is "a subspace which scopes the presence of an object in a given medium." They say that a connection between users is not made until their relevant auras collide. We extend this work by contributing an understanding of what can happen to the involved bodies when not only their auras collide, but their bodies.

Guye-Vuilleme et al. [1999] focused in their work on supporting bodily communication between users in virtual spaces and highlight the challenge of designing an appropriate "visualization of others' actions." They describe several embodiment options for designers to represent such bodily communication, ranging from a "simple" or "blocky" avatar to realistic embodiment approaches; such a range we discuss later where we elaborate on representations of multiple bodies interacting with each other.

Benford et al. [1996] summarize the different spatial approaches in CSCW in order to derive a "dimension of transportation" to describe to what extent people remain in the physical world or leave their body behind. We draw on this when we discuss how the borderline between physical and virtual space can often be blurry and articulate the different options designers have along the transportation dimension when it comes to supporting multiple bodies. Slater and Usoh [1994] have previously called for "body-centered interactions" and stress that in order to design such interactions, we can benefit from looking at the physical body in everyday reality (which we do in our vignette below).

Overall, prior CSCW works have mostly looked at the role of the body and its different representations in virtual spaces while people are not physically touching or acting interdependently. However, more recent work has also looked into touch and other bodily interactions, and what opportunities augmentation offers here. For example, Doucette et al. [2013] found that when people interact physically, they are really good at coordinating and negotiating access that allows them to avoid touch. However, when moving to a virtual space, they found "dramatic differences" when it comes to avoiding touch, suggesting to us to consider bodily interactions differently between virtual and physical spaces. Research has found that people treat their avatar's personal space as they would their own [Jeffrey and Mark 1999]. However, the virtual space is not identical to the physical space: Researchers found that the virtual space does not have the same social norms as the physical world. For example, people had little issue sitting "in each others' laps" in virtual spaces [Tang et al. 2010]. Prior research has also considered more intense bodily interactions that involve considerable body contact. However, critics argued that body contact is so nuanced that actions even as simple as a handshake might never be mediated through a CSCW system [Nilsson 2004], even though a desire to create technologies that support such body contact certainly exist [Schiphorst 2007]. We learn from these works that any system that aims to support social interactions needs to carefully consider how to represent people's bodies.

2.4. Research Gap: Limited Guidance on How to Design for Social Exertion Play

Our review has highlighted the importance of the body and its interactions with other players' bodies when designing for social exertion play. There are different ways bodies can relate to one another, which can be facilitated by the design of the game and affect the resulting social experience. However, there is only limited guidance about how to design for these different social exertion experiences. To address this research gap, we present an initial understanding of how design can support different ways bodies can relate to one another in exertion games. This will offer a guiding structure to help with the design for social exertion play. Of course, there is a plethora of ways in which players' bodies can interact with one another, more than we can articulate in this article. We do not offer a comprehensive list of bodily interactions between exertion game players but rather a framework for a structured understanding of the ways technology can support a range of different interactions between players' bodies in exertion games. As such, our scope is limited to these interactions; nevertheless, we believe they represent an interesting starting point for future investigations. Furthermore, we articulate the opportunities and the challenges of designing interactive technology to support such social exertion play.

3. BODILY INTERPLAY

"*Bodily interplay*" refers to the extent to which bodies can act on and react to each other. The notion of bodily interplay allows us to concentrate on the bodily interactions between people. We propose bodily interplay as a spectrum or dimension, which means that players can experience anything from "none" or "a little" to "a lot" of bodily interplay. This idea of seeing bodily interplay as dimension is inspired by the work of Frost et al. [2008] who examined social play in children and found a dimension a useful tool to examine the many ways of how children can interact with one another. We agree with Elias et al. [2012b] that different genres of games, such as sports, have many things to teach digital games, and therefore in the next section we use cycling to illustrate the bodily interplay dimension before discussing implications for technology augmentation.

3.1. A Vignette of Bodily Interplay

We believe that traditional sports highlight the wide range of ways players' bodies can act on and react to one another. For example, a cyclist might ride along a riverbank without being aware of any other nearby cyclists (*zero* bodily interplay, i.e., independent play). Another cyclist might join on the other side of the river, cycling in the same direction (the cyclists *know* about each other's exertion actions). Then the cyclists spot a bridge and "the race is on": Whoever reaches the bridge first wins (the cyclists now *compare* their actions as a form of bodily interplay). It should be noted that the cyclists related to one another without any physical contact. The exertion actions they performed with their bodies, by cycling together but separated in space, were enough to interact with one another. Then one cyclist crosses over the bridge to join the other cyclist on the same bike path. This allows the cyclists to interact with each other in additional ways. One cyclist might decide to draft behind the other cyclist, using the cyclist's body for slipstreaming (*matching* bodily action as a form of bodily interplay). The cyclists may decide to cut corners in front of each other, causing the other to slow down (contending for *shared space*). This can become so intense that the cyclists use their elbows to hinder each other in their efforts, or even push each other off the bike, engaging body contact (contenting for *shared bodies*).

We propose that we can learn from this vignette to understand the design of exertion games. We begin by proposing that multiple categories lie along the bodily interplay dimension, ranging from "low bodily interplay" to "high bodily interplay." On the far "low" side of the bodily interplay dimension is independent play, where players act independently, i.e., "zero bodily interplay," where players play alone. The bicycle ride began with one cyclist riding alone, not relating to any other cyclist. Later in the ride,

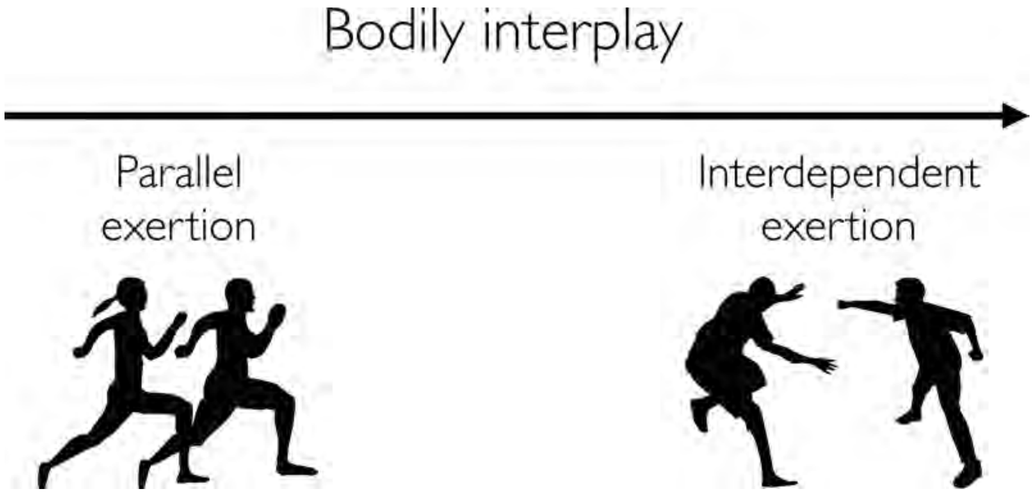

Fig. 2. The bodily interplay dimension.

the degree to which the cyclists relate to one another increased, so the ride moved to the "right" on the bodily interplay dimension, resulting ultimately in an interaction where the riders used their bodies to act interdependently.

3.2. Categories on the Bodily Interplay Dimension

Through a combination of looking at the related literature as well as our own practice of designing exertion games, we propose that there are two key categories on the bodily interplay dimension that are important for exertion game designers: *Parallel exertion* and *Interdependent exertion* (Figure 2).

Using key categories along a dimension to investigate social phenomena is not new. For example, Frost et al. [2008] proposed categories of social play among children existing along a dimension. Similarly, Vossen [2004] argues for distinct categories from a perspective of physical education, where athletes engage in different levels of social play depending on their sport. Even though these authors looked at social play from different perspectives (children's development and physical education), they agree with Rubin [2001] that social play can be placed along a continuum which describes a range of activities from no social play (zero bodily interplay, i.e., independent play) to rich social play.

3.2.1. Parallel Exertion. The parallel exertion category describes experiences in which participants are exerting together, but are acting independently. A typical example from traditional sports is a 100-meter race, in which the runners are not bodily interacting with one another, demarked by the white lines on the track. Other typical parallel exertion activities include Olympic athletic events, such as track and field, road running, race-walking, cross-country skiing, track cycling, synchronized diving, and parallel snowboarding. Other events such as jumping and throwing are also of a parallel nature, and although participants may not undertake the activity at the same time, they are aware of each other's exertion activities in the form of an objective set by another player and therefore engage in social play.

Parallel exertion leans on the notion of "parallel play": Frost et al. [2008] explain that in parallel play, "the child plays independently, and does not try to influence or modify the activity of the children near her. The child plays beside, rather than with, the other children," yet is aware of the other children playing. Similarly, Vossen [2004] says that in parallel play each player performs their exertion actions independently of one another, yet they are aware of each other's exertion actions. The players have no direct influence upon the difficulty of the task faced by other players, as they cannot directly "interfere" with one another [Vossen 2004]. Likewise Elias et al. [2012c] characterize such experiences as those in which "each player is pursuing her own victory condition" while Ernest in "Rules of Play" uses the term "racing game" to describe experiences in which "players are trying to get the most points, and can't directly interfere with other players" [Salen and Zimmerman 2003b].

Researchers concerned with social effects such as Frost et al. [2008] argue that awareness of another player who is also engaging (even without any interdependence, as in parallel exertion) makes a qualitative difference. Moreover, when it comes to exertion, sports science has created a longstanding (although debated [Bond and Titus 1983]) belief in the co-action effects of social facilitation, which suggests that increased task performance comes with the awareness that others are doing the same task. This theory was sparked by Triplett's [1898] early observation that racing against other cyclists rather than the clock alone increased cyclists' speeds.

3.2.2. Interdependent Exertion. The other category along the bodily interplay dimension is "interdependent exertion." It describes exertion experiences in which participants can actively use their bodies to physically act interdependently, which in most sports come in the form of physically interfering or assisting one another. An example from traditional sports is wrestling. Unlike in a 100-meter race, bodily interdependence is core to the experience of wrestling; in fact, any absence of bodily interdependence would render wrestling ad absurdum. Other examples are boxing, American football, soccer, fencing, and basketball. Although we acknowledge that many of our examples are concerned with competitive play, interdependent exertion can also occur as part of collaborative play; for example, see the in-team collaboration in competitive team sports such as the lifting in the line-out in rugby union, where players lift each other in the air to give them a height advantage for catching the ball. Later in the article, we will discuss two case studies with collaborative elements of interdependent exertion.

Similar to interdependent exertion, Frost et al. [2008] identified a category where the child begins to play "with" other children rather than in parallel, arguing that first there is parallel play then play evolves into interdependent play. Elias et al. [2012c] use the term "brawl" and state that in these experiences players "can affect each other's progress, and indeed much of the gameplay centers around just that." Similarly, Ernest stresses that in these experiences, the "object is to take away the other player's points, or to do him as much damage as possible" [Salen and Zimmerman 2003b]. Vossen [2004] calls interdependent actions "non-parallel," highlighting that interdependent is distinctively different to parallel exertion.

3.3. User Experiences in Parallel and Interdependent Exertion

Colloquially, the idea of "race" is often reserved for parallel exertion activities, whereas "sports" is generally used to describe interdependent exertion activities. However, parallel exertion activities are sometimes also described as a sport. For example, a 100-meter athletics race can be described as a race or as a sport, whereas a wrestling match would be titled as a sport.

3.3.1. Exertion Experiences Often Move Between Parallel and Interdependent Exertion. Of course, not all exertion activities are so easily placed within parallel and interdependent categories like our 100-meter race and wrestling. As Elias et al. [2012a] note: "there are of course games that fall in between these two extremes." In particular, exertion activities exist that move between parallel and interdependent exertion within the same game or event. For example, a marathon is typically considered a parallel exertion activity: The rules state that "any competing athlete who jostles or obstructs another athlete, so as to impede his progress, shall be liable to disqualification" [IAAF 2012]. However, the practicality of the marathon race almost always leads to instances where runners cut one another off when going around corners, and sometimes even push each other using their elbows, and as a result their actions are interdependent. It could even be argued that spanning multiple categories across the dimension contributes to the appeal of many sports activities. In the example above, the marathon event might make for a more compelling experience (especially for an audience) as participants are playing with the borderline of what is allowed in terms of bodily interplay, pushing the boundaries of what they get away with in front of race officials.

We also note that our categories naturally encompass a whole range of bodily interactions. For example, interdependent action can involve anything from subtle accidental slapping to forceful pulling and grappling to intense brawling. We are not suggesting that designers would not benefit from considering each of these interactions individually; however, with our two categories, we want to offer an initial guidance into the richer space of bodily interplay by highlighting key areas as they afford different technology considerations, tying together understandings from theory and design craft knowledge in order to begin enriching the field of exertion games.

3.3.2. Tactics. Parallel and interdependent exertion can facilitate different user experiences. In particular, participants of parallel exertion do not have an opportunity to physically act interdependently; hence, the ability to achieve any goal of the activity is determined by the participant's skill and prowess alone. For example, to win a 100-meter race, the only choice a participant has is to run faster than the opponent. In interdependent activities, however, participants can actively use their bodies to physically act on one another and prevent the other player from achieving their goal. As a result, participants can employ tactics such as offensive and defensive strategies as they bodily engage with other participants. This is not possible in parallel exertion.

It should be noted that participants also have the ability to employ tactics in parallel exertion activities. For example, runners in a race could yell at other runners to influence their performance. However, these strategies are not in relation to other participants on a bodily level. In this article, we focus on strategies that occur on a bodily level.

3.4. Sub-categories on the Bodily Interplay Dimension

We now articulate sub-categories along the bodily interplay dimension (Figure 3). Many exertion activities involve a range of individual actions, therefore making the activity span multiple sub-categories, and perhaps increase the appeal of the activity. For example, in basketball, players contend for a shared object (the ball), but also shared space (the best position on the court to fire a shot) and shared body (boxing out to rebound), which altogether make for the exciting activity that is basketball. Our goal with providing such sub-categories is to highlight that there are different opportunities, but also challenges when it comes to introducing technology to these interactions.

3.4.1. Parallel: Knowing. Knowing occurs when players are aware of each other's bodily actions. This characterizes the first sub-category of parallel exertion. A typical example of "knowing" is people exercising together in a spin class. People do not need to engage at the same time. For example, "knowing" can be supported simply by the fact that a person sees a tick mark next to a previous schedule indicating that his/her friend has already participated in a class. By knowing that another person is exerting, psychological effects such as social facilitation [Bond and Titus 1983] could be supported, as participants can improve their performance based on the knowledge that another

Dimension	Category	Sub-category	Description	Example
Bodily interplay	Parallel exertion 	*Knowing*	Players are aware of each other's actions	People exercising together in a spin class
		Comparing	Players compare each other's actions	100-m race
		Matching	Players mimic each other's actions (esp. in synchronous rhythms)	Line dancing; exercising in sync on a rowing machine
	Interdependent exertion 	*Shared Object*	Players use a shared object (e.g. ball) to act interdependently	Ball in tennis
		Shared Space	Players use a shared space to act interdependently	Setting a screen in basketball
		Shared Body	Players use their bodies to act interdependently	Wrestling

Fig. 3. Sub-categories on the bodily interplay dimension.

person is aware of their physical activity. With technology augmentation, new challenges arise (for example, how much awareness does a technology need to support in order to elicit social facilitation effects?), but also opportunities, such as the ability to support time-lapsed training, something very difficult to achieve without technology [Sheridan and Mueller 2010].

3.4.2. Parallel: Comparing. The next sub-category is characterized by players being able to compare each other's exertion, beyond simply knowing about it. This can facilitate the emergence of competition, a key characteristic of most of today's sports activities. Typical examples are athletic races, but also asynchronous activities, such as when players take turns like in athletic throwing events (shot put, discuss, hammer, . . .) or jumping events (long jump, high jump, . . .), where players compare each other's performances one by one.

3.4.3. Parallel: Matching. Human beings have an innate ability to identify and match a beat, which has been previously identified as a key theme for exertion activities [Bernasconi and Kohl 1993; Karageorghis and Priest 2008; Mueller et al. 2011]. The next sub-category is therefore concerned with a player's ability to match a beat of the other player, which can result in synchronous movements, where players move to a uniform rhythm. Typical examples are line dancing, exercising in sync on a rowing machine, and synchronized swimming. Matching exertion can produce strong bodily effects; for example, research has shown that if participants exert in synchrony on a rowing machine, the bodies' pain thresholds can change in a way that allows the participants to exercise harder [Cohen 2010].

3.4.4. Interdependent: Shared Object. The first sub-category of interdependent exertion is "shared object," characterized by players sharing the same object to physically affect each other's exertion actions. A typical example is the ball in tennis, where the player contends to control it in a way that the other player cannot reach it, affecting that player's actions. In contrast to the sub-categories above, "shared object" enables tactical play, as players can play offensively and defensively: A player can use the shared object to either try to achieve his/her goal while also having the option to prevent the other player from achieving their goal. We note that the tennis players cannot physically interact with each other (as their play spaces are separated by the net); however, they use the ball as mediator to act interdependently on one another's bodies: This can offer unique opportunities for augmentation (which we describe later). This is in line with Bekker et al.'s [2010] work that highlighted how offering a shared play object can stimulate a qualitatively different social interaction compared to providing solo personal objects.

3.4.5. Interdependent: Shared Space. This sub-category is characterized by players' abilities to physically affect other players using their bodies via a shared space. For example, a basketball player can set a screen by stepping into another player's way, making them go a different route. Another basketball example is a fake shot, where a player aims to create space by making his/her opponent jump. It is important to note, however, that the player is not physically moving the other player, for example by pushing them in a different direction. Hence, this sub-category is only concerned with affecting other bodies by means of the shared space these bodies occupy, but not direct body contact, contrasting the next sub-category. "Shared space" as a sub-category is a direct consequence of players having bodies that always occupy a certain space that cannot be occupied by someone else (in contrast to, for example, virtual bodies, which we describe below). Similar notions are expressed in articulations on embodied interactions, where one key characteristic is the sharing of mutually exclusive space [Dourish 2001a], i.e., if I am "here," you cannot be "here" at the same time.

3.4.6. Interdependent: Shared Body. This sub-category is characterized by participants' abilities to directly control other players' bodies, hence we call it "shared body." In this sub-category, players experience body contact and utilize it as part of gameplay. The focus is on physically moving the other player by striking, holding, grappling, or even throwing (as in wrestling) the other player. This includes bodily stopping actions such as blocking and parrying in boxing.

Supporting body contact has been previously highlighted as an important but yet little explored area in HCI [Hobye and Löwgren 2011]. Of course, such body-to-body interactions come with a wealth of social and cultural implications [Andersen and Leibowitz 1978], including possible feelings of awkwardness and discomfort [Huggard et al. 2013]. Prior work on proxemics play [Mueller et al. 2014] and uncomfortable interactions [Benford et al. 2012] has highlighted these issues and also described strategies for technology design to reduce, but also exploit them. Benford et al. [2012] stress that there are important benefits for users when systems make them uncomfortable, such as entertainment, enlightenment, and sociality. Shared body interactions are particularly prone to facilitate such uncomfortable interactions, and as Benford et al. [2012] point out, any augmentation with technology will need to take this into account. This raises interesting questions; for example, many sports separate boys and girls into different teams once reaching a certain age (mostly puberty, a time full of uncomfortableness). In traditional sports, this is accepted practice; however, in digital games, this is not. With the increase in range of bodily interplay in exertion games, we might need to think about how we address such issues as a result of "shared bodies."

4. BODILY INTERPLAY IN THE VIRTUAL SPACE

So far, we have examined bodily interplay in traditional physical exertion play. We have not yet paid devoted attention to the digital manifestation of exertion games. In this section, we discuss bodily interplay in the virtual space of play, allowing us to highlight challenges and opportunities for interactive technology in exertion games. We argue that by looking at instantiations of bodily interplay in the physical and in the virtual space of play, we can span a two-dimensional design space that can be used to point out unexplored areas.

Most computer games feature some sort of virtual space [Juul 2005] and likewise exertion games also often feature a virtual space. However, exertion games, unlike traditional mouse and keyboard games, put much more emphasis on the physical space due to the bodily action involved. By physical space, we mean the space in which the players act using their bodies, whereas the virtual space is the space that is inhibited by their bodily representations. In many exertion games, the difference between these two spaces is quite distinct and easy to spot: There is the physical space, such as the living room, in which players move their bodies, and on the screen is a depiction of a space (often three dimensional) that is inhabited by the players' avatars, representing their bodily movements. However, technological advances, in particular around wearables, have led to a blurring of these traditionally distinct spaces, as bodily representations are no longer restricted to discrete virtual spaces. For example, see the work on the game Propinquity [Williams et al. 2010], which uses a traditional exertion game setup in terms of the physical space (two players occupying a demarked space), but without a traditional screen. Instead, players wear digital representations of their virtual health in the form of lights attached to their limbs. Examples like this show how the traditional boundary between physical and virtual space can be blurry, resulting in what Benford et al. [1998] call a mixed reality space.

Our analysis aims to capture these mixed reality experiences. We therefore see the distinction between physical and virtual space as not clearly demarcated. Nevertheless, we believe some knowledge of the difference between the physical and the virtual spaces is important. The recognition of the virtual in a physical setting is useful to understand the opportunities and challenges when considering the digital in bodily interplay. In particular, we found this approach helpful in our own practice of analyzing, developing, and teaching exertion games, and hope that others can benefit from it. We begin by looking at the two spaces as they afford distinct opportunities and challenges.

The use of different spaces to understand digital play experiences is not new. For example, Nitsche [2009] argues that there are different spaces that play a role when examining digital games; we focus on two of these spaces: The physical space the players' bodies occupy and the virtual space the digital technology affords. We acknowledge that some authors believe that differentiating between these spaces is not always beneficial (and, for example, advocate a notion of common place instead) [Dourish 2001a; Dourish and Harrison 1996]. However, we find the use of space a practical starting point as the virtual space in exertion games (like in most digital games [Nitsche 2009]) is often a three-dimensional space based on or expanding our understanding of the world around us. We propose that looking at these spaces can be a beneficial abstraction as they keep our core concepts of interest (bodily interplay in the physical space and any virtual representations) intact while providing an adequate level of abstraction to encompass a wide range of games.

Bodily interplay in the virtual space draws heavily from bodily interplay in the physical space; however, it is concerned with how the bodies' digital representations, not the physical bodies themselves, relate to one another. As exertion games are controlled by bodily effort [Mueller et al. 2003], this effort must be sensed and processed using digital technology. The result is a digital representation of the player's bodily effort. An example of such a digital representation could be an avatar on a screen. Alternatively, an exertion game system might sense heart rate data and display it in the form of numbers. What is important here is that digital representations of players' bodily efforts are a key characteristic of exertion games, and we therefore need to look at the virtual space these representations inhabit if we want to truly understand what opportunities and challenges the digital affords when it comes to supporting social play. In particular, we propose that an instantiation of the bodily interplay dimension in the virtual space can help us to see how these digital representations could interact with one another, and as such, expand our understanding of social play in exertion games. To explore this, we begin in the next section with articulating how, similar to the bodily interplay dimension in the physical space, bodily interplay in the virtual space can have two broad categories: "virtual parallel exertion" and "virtual interdependent exertion."

4.1. Virtual Parallel Exertion

Virtual parallel exertion refers to digital effort representations that act in parallel with no ability to act interdependently with one another. An example that engages virtual parallel exertion is the Fitbit pedometer system [Fitbit 2012] that measures a user's daily step count. The goal of the associated game played on a mobile phone is to reach the highest step count among friends. This is a typical case of virtual parallel exertion as participants are not able to act interdependently with one another's digital representations: For example, a participant is not able to prevent another player from reaching a higher step count number.

4.2. Virtual Interdependent Exertion

Virtual interdependent exertion refers to digital representations of physical effort with the ability—through their players—to act interdependently with each other. As an example, we can imagine a version of the step count system above in which participants can act interdependently with each other's digital representations. A game rule could allow participants who are far behind to trigger a "road block" that prevents the person with the highest step count to increase theirs until the other players have caught up.

4.3. Sub-categories on the Bodily Interplay Dimension in the Virtual Space

We now identify analogical sub-categories of bodily interplay in the virtual space based on our articulation above of the bodily interplay dimension.

4.3.1. Parallel: Knowing in the Virtual Space. Designers can support players knowing about each other's exertion through the virtual space. For example, a game could send a status update to a person, indicating that their friend is playing an exertion game. This would allow players to know that their friend also invests effort through the use of the virtual space, all while not seeing each other. For example, designers might want to consider this sub-category when developing games for obese participants to avoid feelings of evaluation apprehension [Hagger and Chatzisarantis 2005] due to fear of social judgment.

4.3.2. Parallel: Comparing in the Virtual Space. The next sub-category is characterized by players not only knowing about each other's exertion, but also being able to compare it. The virtual space offers a unique opportunity here. For example, runners might like compare to each other: In the physical space, they can see who runs faster. However, in the virtual space, they can use an app to not only compare speed but also their accumulated weekly distance and average monthly pace.

4.3.3. Parallel: Matching in the Virtual Space. The virtual space also offers opportunities for players to match each other's bodily "beats," for example supporting synchronous movements. Again, the digital offers unique opportunities here: For example, if a game tracks player movements with a camera, the software could identify a particular movement beat and stress it by amplifying it through overlaid visuals, supporting the other player to identify the beat and therefore making it easier to synchronize to that rhythm.

4.3.4. Interdependent: Shared Virtual Object. In the "interdependent" category, the sub-category "shared virtual object" refers to players sharing a virtual object that allows for affecting each other's exertion actions. A typical example is the virtual ball in Kinect table tennis that both players are aiming to control. Again, the digital offers unique opportunities here: The shared virtual ball enables players to play over the internet, supporting players in separate locations, something that cannot be achieved with traditional table tennis.

4.3.5. Interdependent: Shared Virtual Space. This sub-category is characterized by players' abilities to affect each other via a shared virtual space. For example, an avatar might step into the path of another avatar, and by doing so prevent the other avatar from achieving the game's goal. We note that in contrast to the physical space, in the virtual space the designer has control over the shareability of the space: They can toggle collision detection on or off to enable/disable this feature.

4.3.6. Interdependent: Shared Virtual Body. This sub-category is concerned with virtual representations being able to affect other virtual representations through contact. Mostly, this unfolds in the way avatars experience "body" contact, where one avatar affects another avatar. An example is Kinect boxing [Wikipedia contributors 2012], where an avatar can hit the other. Again, the digital offers additional experiences beyond simply replicating body contact in the virtual world: For example, instead of hitting, avatars could also "reach" into other avatars. Other examples are games in which two players control one avatar together, so they are literally sharing a virtual body. Again, we stress that our sub-category is only a starting point toward beginning considering these experiences and does not provide a complete account of all the different experiences, rather it aims to initiate a discussion of how people can experience shared virtual bodies and how we can leverage this knowledge in exertion game design.

5. DESIGN SPACE OF SOCIAL EXERTION GAMES BASED ON BODILY INTERPLAY

Having articulated two instances (physical and virtual) of bodily interplay, we can now scaffold a two-dimensional design space, which helps to articulate differences in approaches to exertion game design and identify design opportunities (Figure 4).

We find that many existing exertion games mirror the bodily interplay from the physical space in the virtual space. They sit on a 45-degree angle across the design space and we call them Comparative Coupling and Projected Coupling games. However, we note that game designers also have the opportunity to facilitate experiences that support types of bodily interplay in the virtual space that differ to the physical space.

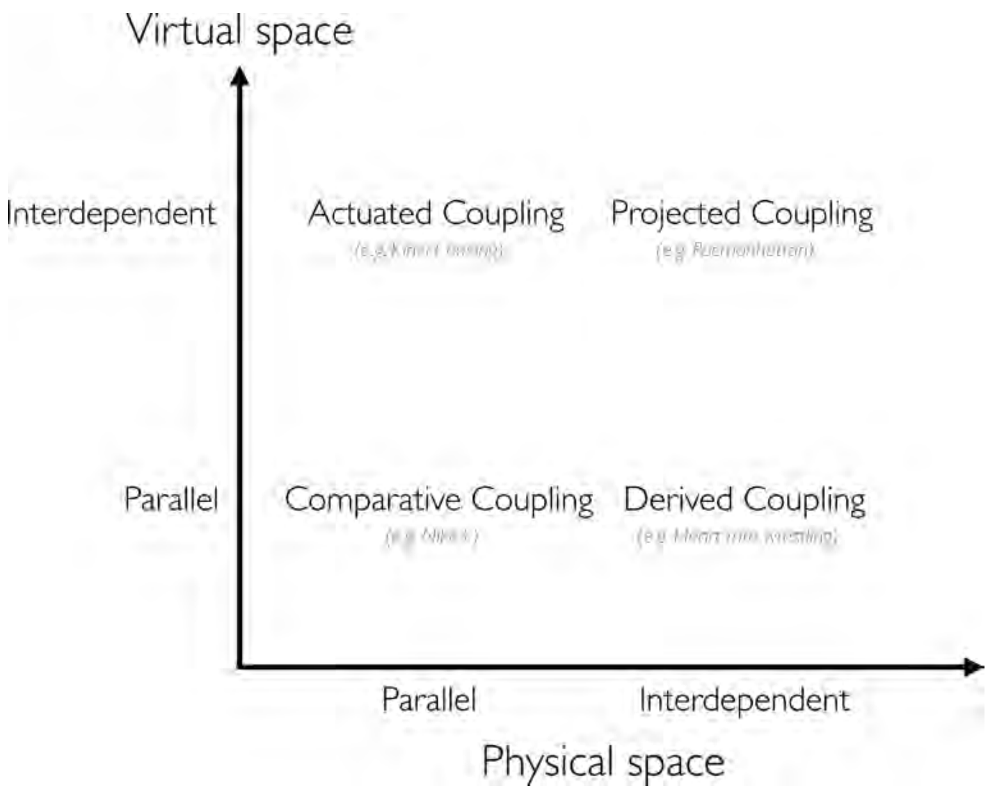

Fig. 4. Design space of social exertion games.

This is a unique opportunity for exertion games, thanks to the virtual space. We call them Derived Coupling and Actuated Coupling games.

5.1. Comparative Coupling

In the bottom-left of Figure 4, we see games that offer parallel exertion in both the physical and virtual space. This means that neither the participants' bodies nor their representations have the opportunity to interact with one another. We use the term Comparative Coupling because the coupling between the physical and virtual space supports the comparison of exertion between players. In this part of the design space are examples such as the Nike+ app [Nike+ 2015] that allows for sharing a user's running data online with other joggers, supporting comparisons such as "who ran the farthest?" The joggers run on their own, being physically independent, and the virtual representations of this running data are also not able to act interdependently with one another: Each jogger is represented by an avatar that runs along their own performance graph.

We now articulate design opportunities and challenges, in particular those associated with benefits and limitations of today's technology. Based on our design and teaching practice, we use our bodily interplay dimension to also articulate strategies for representing exertion across the four sections of the design space in order to aid designers in delivering engaging social exertion experiences.

5.1.1. Opportunity: Enhanced Comparisons. Technology deployed to capture exertion often quantifies it in a way that allows players to compare it. Advanced sensors support such endeavors to an unprecedented accuracy: For example, time-keeping technologies in a 100-meter race can offer accuracy that the human eye cannot match. In other words, the technology enables comparisons where humans are not able.

Technology can also enable new types of comparisons. For example, the biathlon game [Nenonen et al. 2007] uses heart rate data as input to a race-type game. Without technology, manually measuring and comparing heart rate can be tedious and distracting during a sports activity. In contrast, technology can capture heart rate in a relatively unencumbered manner, allowing for a new type of race experience.

Comparative Coupling games also offer another opportunity: As participants are not acting interdependently, Comparative Coupling games lend themselves to asynchronous experiences, supporting, for example, players across time zones [Mueller 2010]. Similarly, the lack of interdependence makes the balancing between participants of different physical abilities relatively easy. For example, internet-enabled exercise bike systems such as Tacx [2009] allow less-fit cyclists to cycle with more advanced cyclists by providing them with a faster avatar.

Furthermore, since many contemporary technologies are still rather fragile and need to be handled with care, these technologies appear to suit games in this section of the design space as they do not need to be concerned with forceful and hence technology-damaging body-to-body interactions. This might explain why many of today's commercial exertion games are situated in the Comparative Coupling section. However, this section of the design space also brings forward challenges that arise due to the parallel nature of the experience and we will next make suggestions how to address them.

5.1.2. Challenge: Playing Alone. Comparative Coupling games can pose challenges for designers when it comes to supporting social play. Even though players can relate to one another, it is important to note that they do not have to, so their experience can easily turn into a solitary rather than a social experience; in essence, players might end up "playing alone." This is a concern known from button-press games that seemingly support social play, yet players play "alone together" [Ducheneaut et al. 2006]. We find that a virtual space can draw focus on the independent aspect; for example, running a 100-meter race with others affords certain social effects: Participants can easily compare their results, but they can also look at each other during the race and listen to each other's panting. In contrast, the appeal of the digital can "pull players in," attracting their focus [Juul 2005; Voida et al. 2010], and hence take away attention from the physical space, where the traditional affordances for social play through co-presence are not prevalent. Therefore, designers who create Comparative Coupling might need to consider more explicitly how to support social play in comparison to games without a virtual space.

5.1.3. Strategies for Representing Exertion. We find that designers have a wide range of options for representing exertion, and we believe that our design space can help identify particular strategies. We present several example games later in the article that can be used to illustrate these strategies; however, we developed the strategies later so the games were not designed to demonstrate particular strategies. We are inspired by Dourish's [2001b] discussion on embodied representations and use an iconic/symbolic dimension that describes the relationship between "a representation and whatever it represents." We concentrate on representations of exertion, most notably signs of exertion and exertion activity as well as signs that stand for exertion, such as sweat and movement, as they can be readily sensed by interactive systems [Mueller et al. 2011]. In particular, we draw from previous HCI investigations into the three key types of representation: icon, index, and symbol [Joost and Hemmert 2010]. First, we use the term "iconic representation" to denote representations of exertion that resemble exertion activity. A typical example is an avatar that moves with the player; it is a representation of the player’s movements in the virtual space. Second, we use the term “indexical representation” to denote representations that have an actual connection such as correlation in space and time with the exertion. A typical example is a virtual car that is controlled by a person pedaling on a stationary exercise bike: The faster the person pedals, the faster the car moves. Third, we use the term “symbolic representation” to denote representations of exertion that primarily get their meaning from mental associations with other symbols, for example the number “180” to represent heart rate.

Through our design as well as teaching practice around exertion games, we find that iconic representations like avatars are well suited in all sections of the design space. However, we also find that indexical and symbolic representations are particularly suited to the Comparative Coupling section and therefore engaging avatars without considering these other options might be a missed opportunity. In particular, it can often be simpler to implement symbolic and indexical representations. For example, displaying a number as effort representation can often be achieved simply, whereas implementing an avatar representation usually requires a high-definition display, specific modeling skills, a camera sensor, and costly image analysis processes.

Symbolic representations are particularly well suited to Comparative Coupling games as they allow participants to compare their effort and hence support the race characteristic of these games. For example, designers can choose to represent players’ movements with symbolic representations such as numbers. Indexical representations are also well suited in this section of the design space, as the parallel nature of the experience emphasizes independent exertion actions, which designers can apply to independently moving virtual objects. For example, in the Tetris Weightlifting system, players can move Tetris blocks within their split-screen virtual worlds by pulling on a bodybuilding exercise machine [Tucker 2006].

5.2. Actuated Coupling

We use the term Actuated Coupling to characterize games in which the coupling between the physical and virtual space facilitates an actuation between players, providing an opportunity for an interdependent experience despite the lack of interdependence in the physical space. Many commercial exertion games that run on the major game consoles are Actuated Coupling games. For example, the Kinect boxing game [Wikipedia contributors 2012] features avatars that can hit one another. These boxing avatars act interdependently because an avatar’s hit can impact the other avatar and the avatars can also block hits. The players, on the other hand, are not acting interdependently when it comes to their bodies.

5.2.1. Opportunity: Tactics Without Body-Contact. Designers who aim for this part of the design space have the opportunity to facilitate exertion experiences that support tactics (such as offensive and defensive play) without needing to be concerned about body contact (and any associated negative connotations). Designers who aim to support these types of games also have the advantage of being able to utilize existing sensing technologies such as the Wii bar and Kinect, allowing easy entry points into this part of the design space.

5.2.2. Challenge: Decoupling of Avatar and Body. The challenge for designers arises from the mix of parallel and interdependent play, as it can lead to situations where virtual actions do not link back to physical ones. For example, player A might use their avatar to push player B’s avatar. B’s avatar experiences this movement; however, player B has not moved as there is no interdependence in the physical space. The initial tight coupling between player B and his/her avatar is disrupted, with the avatar and body becoming unlinked as a result of the other avatar’s interdependence. We now articulate several strategies for how designers have previously dealt with such a potential decoupling of avatar and body by taking Wii Boxing as an example.

In Wii Boxing, players' fist movements are sensed using the Wiimote and mapped to virtual gloves worn by virtual boxers. If a player strikes with the fist, the virtual boxer strikes with the virtual glove. It gets interesting if a player strikes and hits the other virtual boxer's glove, because the glove being hit retracts based on impact. This moving back of the other virtual boxer's glove poses an interesting question: What happens to the other player and their fist? The players do not experience body contact as they are not hitting each other. So if a virtual glove makes another virtual glove move, what happens to the other player's physical fist? In Wii Boxing, the physical fist is not moved (designers who want to achieve this could, for example, deploy electronic muscle stimulation). This means that the coupling between virtual glove and physical fist is temporarily disrupted. The game designers implemented four strategies to address this: First, they provide haptic feedback through the Wiimote that indicates to the player that a decoupling occurred. Second, they quickly move the virtual glove back into its original position to re-establish the coupling. Third, the cartoon-like character of the avatars contributes to the fact that players are able to engage, despite any brief decoupling: Players are reminded that the avatar is a playful representation, situated in a games context, where avatars often act independently and so decoupling is not very unexpected. Fourth, the game play is designed to be fast and erratic (as players are encouraged to hit often and quickly) so that the player's focus is on the fast interaction, making the decoupling difficult to notice.

5.2.3. Strategy for Representing Exertion. We recommend designers of Comparative Coupling games give particular consideration to iconic and indexical representations as these games engage interdependent actions that often draw on quick bodily actions and reactions from the players. The representations can therefore benefit from a close resemblance to the actions in the physical world. However, it should be noted that supporting such iconic and indexical representations is often challenging to implement; for example, designers should be aware that in many cases advanced sensor systems might be required as they need to respond to the often fast tactical play with rapid actions and reactions.

5.3. Derived Coupling

In the lower right hand of Figure 4 are games in which participants' bodies can act interdependently, yet their virtual representations lack this opportunity. We use the term Derived Coupling as the interdependence in the physical space derives a parallel experience in the virtual space. We do not know of many games that have such a characteristic. However, we can envision the game "Heart rate wrestling" in which participants wrestle with one another while their heart rates are sensed to control the speed of participants' avatars on a virtual racing track. The goal is to get one's avatar across the finish line first, so the players try to wrestle in a way that increases their heart rate in order to speed up their avatars. In this game, participants' bodies are acting interdependently through the act of wrestling; however, their virtual representations are not. This can facilitate a novel user experience: Participants wrestle to raise their heart rate, while at the same time try to keep their partner's heart rate down, which will be difficult to achieve. From our experience, this part of the design space is relatively unpopulated, suggesting new opportunities for designers.

5.3.1. Opportunity: New Social Experiences. Designers who aim for this part of the design space have the opportunity to facilitate new types of social experiences when compared to non-augmented exertion activities, such as the "Heart rate wrestling" game described above. Furthermore, Derived Coupling offers the advantages of interdependent play without the need for complex technology such as force-feedback, as there is no need to offer feedback from other bodies back into the physical world.

5.3.2. Challenge: Addressing Existing Expectations. The challenge for Derived Coupling designers is creating a successful mix of parallel and interdependent aspects while ensuring a meaningful play experience. Most traditional sport experiences either focus on parallel or interdependent actions. Here, thanks to the introduction of digital technology, game designers have the ability to support both, but in a way that challenges participants' existing expectations about how exertion experiences unfold. There are simply not many examples out there where players experience interdependence in the physical and parallel play in the virtual space. Many exertion game players have expertise in and expectations from previous sports experiences and cultural knowledge about sports that suggest that interdependent actions will result in interdependent play. With Derived Coupling, game designers can challenge this, but they need to be aware that such an approach might require thoughtful consideration on how players are introduced to and engage with these new types of experiences.

5.3.3. Strategy for Representing Exertion. We recommend designers consider the potential of symbolic representations, as they lend themselves to parallel play as discussed previously. The Heart rate wrestling game example shows how a heart rate monitor could sense heart rates displayed on a screen that denotes a heart rate race. Even though participants engage in quite complex bodily interactions, the sensing and display technology for this type of game could be basic, highlighting an implementation advantage for games in this section of the design space.

5.4. Projected Coupling

In the upper-right-hand corner of the design space are games in which participants' bodies as well as their virtual representations have the opportunity to act interdependently. We use the term Projected Coupling as the interdependence in the physical space is projected to the virtual space.

Pacmanhattan as well as many other similar pervasive games [Montola et al. 2009] are situated in this part of the design space. These games are characterized by players occupying a shared physical space, such as a city block, that is represented in the virtual space, most often a 3D representation of the same city block, where players are represented as avatars. Pacmanhattan is a version of the original Pacman game that is played on the streets of Manhattan. A player dressed as Pacman runs around Manhattan to collect virtual dots. Videos indicate how participants used their bodies to act interdependently: They were blocking others to cross streets in their attempt to catch the Pacman player. In the virtual world, the avatars also acted interdependently; for example, the rules state that once Pacman and a ghost occupy the same space, the game is over. As such, Pacmanhattan is a game that features interdependence in both the physical and virtual space and therefore is a Projected Coupling game.

5.4.1. Opportunity: Amplifying Experiences. Designers also have the opportunity to support interdependent constellations beyond simple one-to-one mappings, for example by altering the representations in a way that any exertion actions amplify (or dampen) the impact they have on the experience. A slight push from a player to distract another player (which might have only limited consequences in the physical world) could result in dramatic consequences in the virtual world changing the impact of the push. Therefore, the virtual space in Projected Coupling games offers new ways to affect how interdependent elements can unfold.

5.4.2. Challenge: Supporting Tight Coupling. The challenge arises from the tight coupling between bodies and their virtual representations. As other players have the opportunity

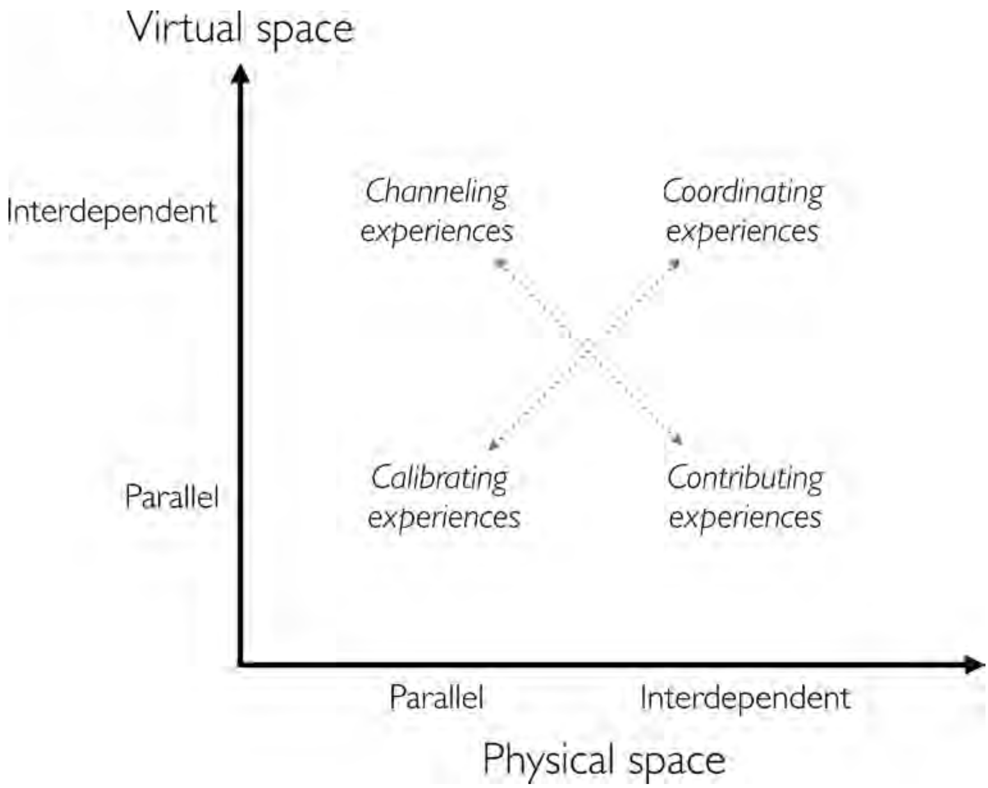

Fig. 5. Four approaches to the player experience.

to affect a player's virtual representation, this action is ideally linked back to the body via a tight coupling. A common way to implement this is by employing force-feedback technology. In particular in sports science, where the focus is often on simulating exertion actions as accurately as possible, there exist many works where force-feedback technology is employed, for example see von Zitzewitz et al.'s [2008] work. However, utilizing force-feedback approaches can often be expensive, complex, limited in the range of actions and intensities that are supported, and cumbersome to operate. Designers should be aware of these limitations when considering Projected Coupling, thinking about implications their approach might have on any tight coupling.

6. FOUR PLAYER-EXPERIENCE APPROACHES BASED ON BODILY INTERPLAY

In this section, we describe four general approaches to player experiences based on the four couplings we articulated above (Figure 5). Of course, these approaches are only indicative at this stage and describe rather broad player experiences; however, we hope they provide designers with a view on the possible player experiences they can expect by pointing them toward the four corners of the design space.

6.1. Calibrating Experiences

The more the game moves into the lower left of the design space, the more the player experience will have a calibrating character. With unimpeded reference to comparative data and immediate feedback, users can easily calibrate their physical effort within their own effort range and with respect to that of their opponent. This type of experience is akin to a race, where comparing achievements is a key aspect of what players experience. Players can compare exertion achievements in both the physical and virtual space, but also across the two spaces, allowing players to engage in a wide range of comparisons.

6.2. Channeling Experiences

The more the game is situated in the upper left of the design space, the more the player experience will be of a channeling character. With physical freedom but virtual interdependence, users can channel all their attention to the mediating virtual representations. This is cemented further by the fact that interdependence is supported in the virtual space, which is not commonly associated with negative connotations like uncomfortable bodily proximity and body contact, facilitating explorations of virtual bodily interactions that social norms might prohibit in the physical space.

6.3. Coordinating Experiences

The more the game is situated in the upper right of the design space, the more the player experience will be of a coordinating character. As interdependence is supported in both the virtual and physical space, players can utilize the advantages of both to engage in experiences that make use of the matching coupling between the spaces. However, players will need to pay close attention to both spaces and coordinate their actions in each space with respect to the other.

6.4. Contributing Experiences

The more the game is situated in the lower right of the design space, the more the player experience will be of a contributing character. With players engaged in physical interdependence, their ability to pay attention to virtual representations is diminished. Players interact physically knowing that their physical actions contribute to virtual outcomes in a selectively interpreted manner. Players will therefore be curious about what results their actions will have in the virtual space, facilitating experiences filled with surprise and suspense. This is cemented further by the fact that the interdependence in the physical space allows players to act on and react to their game partners, adding to the suspense that comes from opening oneself to the actions of another player.

7. APPLYING THE BODILY INTERPLAY DIMENSION

We believe our work can be useful when it comes to identifying a design opportunity and coming up with a game idea, but also when it comes to developing a more concrete game. In particular, our work might be useful when designers consider the sensing and actuating technologies available to them, helping them evaluate any potentials and limitations in terms of the gameplay they aim to support. Also, we believe our work can be used to consider design alternatives to existing prototypes in an attempt to facilitate novel gameplay experiences.

In the following sections, we describe how our conceptual thinking can be readily applied to concrete design examples to demonstrate its utility. Our framework has been applied to the design of three of our own social exertion games and one commercial system: a table tennis game for three players in three different locations; a mobile system for joggers that uses spatialized audio controlled by heart rate; a distributed shadowboxing game; and the Xbox "Kinect Adventures" game. These social exertion games support a variety of different physical actions (hitting a ball, endurance running, striking another body, leaning, and jumping); are intended for use in different environments (jogging outdoors while table tennis, shadowboxing, and Kinect Adventures are played indoors); target different numbers of players (two in jogging, three in table tennis, two to four in shadowboxing, and two in Kinect Adventures); use different sensing approaches to exertion (heart rate in jogging, detecting ball actions in table

Fig. 6. Jogging over a Distance.

tennis, hitting actions in shadowboxing, time-of-flight sensing in Kinect Adventures); and deploy different output technologies (audio-only in jogging, video and audio in the other three games). All our own systems exploit the potential of networking advances to enable playing over large distances [Mueller et al. 2003], and hence illustrate how our thinking about bodily interplay is applicable to distributed settings while highlighting the unique opportunities and challenges that arise from this.

8. EXAMPLE 1: JOGGING OVER A DISTANCE

Jogging over a Distance (JoD) is a jogging support system that uses heart rate data to control spatialized audio between geographically distant joggers [Mueller et al. 2007; Mueller et al. 2012; Mueller et al. 2010a; Mueller et al. 2010b]. The aim of the system is to support "social joggers," i.e., people who use exercise to socialize and socialize through the exercise [O'Brien and Mueller 2007]. Within JoD, two joggers plan to run at the same time, wearing stereo headphones, a microphone, and a heart rate monitor (Figure 6). Each jogger can hear the live audio of their jogging partner while they run. Relative to their target heart rate (which the joggers enter beforehand), the jogger's heart rate data affects the audio location in a 2D plane oriented horizontally around the jogger's head. If the other jogger is "in front," the sound appears to come from the front, and the further "in front," the softer the audio volume. When both joggers perform at their preferred heart rate (or have both slowed at the same percentage from their baseline), they hear the audio right beside them, as if they were running side-by-side. The spatialized audio therefore acts as a sign of relative effort and tells the joggers when they need to speed up or slow down to "stay" with their partner [Mueller et al.

2007]. JoD has been studied with over 30 participants as far apart as Australia and Europe, showing that it can support a social "jogging together" experience despite the geographical distance [Mueller et al. 2010b].

We now discuss where we encountered design challenges, which inspired us to develop the bodily interplay dimension, and instances where we applied the bodily interplay dimension to redesign the JoD system.

8.1. Bodily Interplay in Jogging Over a Distance

8.1.1. Bodily Interplay in the Physical Space. Joggers do not usually act interdependently, and in particular the joggers in JoD cannot physically act on one another due to the geographical distance between them. Therefore, there is a low degree of bodily interplay in the physical space; in fact, if we would not have told the participants that their partner is jogging at the same time, they would not have been aware of their partner's exertion. As such, the low degree of bodily interplay makes this a parallel exertion activity in the physical space.

8.1.2. Bodily Interplay in the Virtual Space. Bodily interplay is supported in the virtual space through the audio. Initially, we connected the joggers with mono Bluetooth headsets, which allowed them to know ("knowing exertion") about each other's exertion, as they could interpret through their partner's breathing and environmental noises (footsteps, etc.) that the other person was also investing effort [O'Brien and Mueller 2007]. Interviews with participants revealed that they enjoyed this system [O'Brien and Mueller 2007]; however, the ability to "push" one another, as known from co-located jogging, was limited. In response, we introduced stereo headsets and constructed a 3D audio environment around participants' heads delivered through the headphones. This allowed participants to compare each other's exertion investment, allowing them to "push" one another, and therefore moving the experience from the "knowing" to the "comparing" sub-category.

This design alteration highlights how we exploited the virtual space in terms of bodily interplay; by allowing for comparisons in the virtual space, we enabled joggers to compete, while at the same time the distributed nature of the physical space prevented any possibilities for participants to physically act on one another. This also meant that any opportunities to engage bodily tactics (such as cutting the other person off) were not possible in JoD.

8.1.3. Explaining and Extending Jogging over a Distance Through the Design Space. We now examine JoD through the design space to clarify the advantages of our design while also articulating opportunities to extend JoD (Figure 7). For the joggers, their bodily actions are of a parallel nature in the physical world, as they cannot act on each other because they are geographically apart. We drew on this during our design phase and made the actions in the virtual world also parallel: Our joggers could not act interdependently in the virtual space. JoD is therefore a Comparative Coupling game.

However, the bodily interplay dimension also highlights that the parallel nature of the virtual world has an interesting characteristic: Our joggers were able to occupy the same spot in the virtual space if they were both investing the same physical effort. This is different to jogging side-by-side, where joggers cannot be in the same spot where their partner is: If a jogger moves closer to his/her partner, it might at first get uncomfortable, then potentially dangerous because of stepping into the other's way, leading to tripping and injury. As such, JoD can be considered as having an even "more" parallel characteristic than traditional jogging thanks to the virtual world.

Awareness of this "more parallel" characteristic can guide and inspire future iterations: For example, if a jogger is "behind" but wants to get "in front," they can currently simply run "through" their partner; however, we could also implement it in a way that

<table>
<tr><th>Coupling</th><th>Physical space</th><th>Virtual space</th></tr>
<tr><td>Comparative Coupling</td><td>Knowing</td><td>Comparing</td></tr>
<tr><td colspan="3">This variation of JoD connects the jogger with other runners who are also using the same system while running in the same park (using GPS to sense nearby runners). So the jogger knows that there are other joggers also running (who she/he can see from a distance), yet the jogger does not know how fast the other runners are. The virtual space provides the jogger with their pace information, however, the system does not tell the jogger whose pace belongs to whom, offering the jogger a guessing game of who is faster/slower when coming across another jogger (comparing), turning the exertion activity into one of intrigue (allowing for calibrating experiences).</td></tr>
<tr><td>Actuated Coupling</td><td>Independent</td><td>Shared space</td></tr>
<tr><td colspan="3">The joggers run in physically separate locations, independently. The virtual space provides the joggers with a shared audio space (shared space), where the game's objective is to "catch" the other jogger by running in the direction of the other jogger's sounds representation (facilitating channeling experiences), motivating the exploration of the physical environment. Once a jogger "catches" the other, his/her audio source is spawned in another location, and the other player now has to chase that audio source.</td></tr>
<tr><td>Projected Coupling</td><td>Shared object</td><td>Shared body</td></tr>
<tr><td colspan="3">In this game, two joggers run together, sharing a drink bottle as a shared physical object (shared object) that can be used to motivate the jogging partners to stay close. The bottle is augmented, providing the joggers with information about who drank how much, and how many bodily reserves each have (through biosensors), supporting the notion of a shared body, with the goal being to arrive at the finish line together, so the jogging partners need to manage their resources collaboratively (allowing for coordinating experiences).</td></tr>
<tr><td>Derived Coupling</td><td>Shared body</td><td>Comparing</td></tr>
<tr><td colspan="3">In this game, two joggers are connected by having to hold onto a shared relay baton (shared body). Winner of the game is who increased their heart rate the most (comparing) while running holding the baton together (allowing for contributing experiences).</td></tr>
</table>

Fig. 7. Using the bodily interplay dimension to extend Jogging over a Distance.

extra effort is required to "run around" the other person in the audio space. This extra effort could come in the form of an increased heart rate the jogger needs to achieve, or, with additional sensors, the jogger might be required to "step aside" their straight jogging path to overtake the other jogger. Alternatively, the system could highlight that running exactly "in the same spot" as the partner is possible, for example by rewarding it through playing additional sound cues.

The design space also helps us envision a move for JoD into the Actuating Coupling section. For example, we can envision a version where, if a jogger falls behind, it

Fig. 8. Table Tennis for Three.

is not possible to overtake the other jogger anymore as long as they keep running. This could motivate users to keep running by allowing them to "block" their partner from overtaking. By implementing this, JoD would become an Actuating Coupling experience, supporting probably more competitive jogging types.

We now demonstrate in the figure below how the bodily interplay dimension along with its sub-categories can help us extend JoD by inspiring distinct novel experiences. Designers have a multi-dimensional design space available to them, where they can work through six sub-categories (seven if we also count "independent" exertion) for each space in order to generate design ideas, making for 6×6 (or 7×7) possible combinations. We demonstrate the generative power by providing example combinations across all four couplings, leaving to the reader's imagination how to fill the other combinations with ideas. We describe the coupling for each game as well as the player experience it affords.

9. EXAMPLE 2: TABLE TENNIS FOR THREE

Table Tennis for Three (TTT) is inspired by the game of table tennis, but accommodates three players at three different tables, rather than two players at one table [Mueller et al. 2009].

Each player has an identical setup, which includes a ball, a paddle, and a modified table tennis table. The table is set up so that the ball can be hit against a "backboard"—a vertically positioned opposite half of the table (Figure 8). Digital bricks are projected onto the backboard so that the bricks exist in a virtual space shared by all three players. In addition, side-by-side video feeds of players' opponents are projected behind the bricks, thus creating a sense of "playing together." The goal of the game is for each player to break the bricks using their physical paddle and ball. The bricks crack a little, then a lot, and then break after three strikes from any ball and any player. However, only the third striker receives the point. Play continues until all bricks are broken, and the player with the most points wins. Although the game is competitive in terms of announcing a single winner, a study showed how two players often collaborate in order to engage with a more skilled third player [Mueller et al. 2009].

9.1. Bodily Interplay in Table Tennis for Three

9.1.1. Bodily Interplay in the Physical Space. Players of traditional table tennis as well as TTT players cannot physically act interdependently in the physical world, as they are on separate sides of a table tennis table. Nevertheless, traditional table tennis players can engage in offensive and defensive play, as they are contending for control of the physical ball, this is because the ball is shared ("shared object") and hence allows for interdependent play. In TTT, on the other hand, each player has his or her own ball, meaning there is no physical object that the players share. Similar to JoD above, the physical separation of the players means they are engaging in a parallel exertion experience in the physical space.

9.1.2. Bodily Interplay in the Virtual Space. Two key design aspects of TTT are concerned with bodily interplay in the virtual space. First, the videoconference projected onto the table halves allows the distributed players to know ("knowing exertion") about each other's exertion investment. Players knew how their partners were playing, as they could see them hitting with their bat. Second, the virtual bricks are shared among players, and the ability to break them in stages, including the opportunity to snatch the last crack and hence the point away from one another, allowed players to engage in offensive and defensive actions. This design feature moved the experience to the "interdependent" category.

9.1.3. Explaining and Extending Table Tennis for Three Through the Design Space. If we examine TTT, we can see that the shared virtual object (the bricks) situate the game in the Actuated Coupling section. The support for bodily interplay in the virtual space means that players in separate locations can engage in interdependent play, thanks to the shared virtual object. This allows for a scaling of the player numbers: Three players can play together, something that is not easily achieved in traditional table tennis (where two players would need to play against one, an unequal setup).

Examining TTT's position in the design space allowed us to generate new design ideas (Figure 9): Instead of having shared virtual objects, we can envision a future version that centers on the idea of a shared virtual space. For example, the impact of the ball on the virtual bricks could mark a spot in the virtual space that other players could not occupy: Players' tactics would then center on claiming ownership of shared objects. Another version could incorporate the notion of a shared virtual body, where the players' representations in the video stream are also part of the gameplay: Players would need to place their balls in a way that "hitting" the other player's videoconference image scores a point, which might motivate dodging behavior, facilitating possibly greater physical investment.

10. EXAMPLE 3: REMOTE IMPACT

Remote Impact is inspired by combat sports: Each player interacts with a padded playing surface built out of augmented mattresses [Mueller et al. 2009] (Figure 10).

The shadows from both the remote and the local player are projected onto the surface. Each player tries to make forceful contact with their opponent's shadow without getting "hit" themselves. An impact on the remote person's shadow is counted as a successful hit and an audiovisual effect is played (e.g., "POW!"). Points are awarded according to the force of the impact and the player who scores the most points within a set time limit wins the game.

10.1. Bodily Interplay in Remote Impact

10.1.1. Bodily Interplay in the Physical Space. Traditional combat sports are all about body contact and aiming to control the other body; they are concerned with the "shared

<table>
<tr><th>Coupling</th><th>Physical space</th><th>Virtual space</th></tr>
<tr><td>Comparative Coupling</td><td>Knowing</td><td>Comparing</td></tr>
<tr><td colspan="3">In this game, the two table tennis systems are placed back-to-back in the same room, so that two players can play facing each other, knowing that they are exerting through being in the same physical space. However, they can only estimate how "much" the other person is exerting by looking at him/her. The goal is to hit virtual targets projected on the table. However, they are not shared across the virtual space; so unlike in TTT, it is not a shared object. However, the amount of hits is projected on the tables allowing players to compare their score. The result is a calibrating experience.</td></tr>
<tr><td>Actuated Coupling</td><td>Independent</td><td>Shared object</td></tr>
<tr><td colspan="3">In this game, the players are being physically separate, playing independently in the physical space, as in the original TTT. In the virtual space, however, they share a virtual ball, which they see using augmented reality goggles (shared object), making for an actuated coupling game. The result is a channeling experience.</td></tr>
<tr><td>Projected Coupling</td><td>Shared object</td><td>Shared object</td></tr>
<tr><td colspan="3">In this projected coupling game, two players play on the same TTT table, similar to doubles. They share the same physical ball (shared object in the physical space), aiming to hit the virtual targets (shared objects in the virtual space) known from TTT, but this time in a collaborative fashion, enabling a coordinating experience.</td></tr>
<tr><td>Derived Coupling</td><td>Shared body</td><td>Comparing</td></tr>
<tr><td colspan="3">In this game, two players play on the same TTT table (like above), however, they share an oversized paddle that they swing together (shared body). A sensor measures VO2 max (maximum rate of oxygen consumption) for each player, enabling a comparison of individual exertion intensities, allowing for a contributing experience.</td></tr>
</table>

Fig. 9. Using the bodily interplay dimension to extend Table Tennis for Three.

body." However, the distributed nature of Remote Impact prevents body contact and any bodily control; hence, similar to the other two examples above, we consider it a parallel exertion experience in the physical space.

10.1.2. Bodily Interplay in the Virtual Space. Players' bodies are represented as virtual avatars, through and upon which the players act. As such, players experience a shared virtual space, in which their avatars contend for the same space: Although the avatars could overlap on the projection screen, the goal is to avoid this as per the rules of the game. Therefore, the players aim to position their avatars where their opponent is not (while trying to punish the other player for occupying the same space with a hit).

10.1.3. Explaining and Extending Remote Impact Through the Design Space. Looking at the design space helps us articulate the play opportunities of Remote Impact: Players engage in interdependent actions via a shared space while being in geographically

Fig. 10. Remote Impact.

distant locations, this makes Remote Impact an Actuated Coupling game. This physical separation offers the benefit of preventing bodily contact that could lead to injuries: Although Remote Impact is forceful, participants believed interacting with it to have a low risk of injury, especially when compared to traditional body contact combat.

Examining Remote Impact's position in the design space also highlights how we can articulate specific player experiences we identified through observing and interviewing players; in particular, we now have a vocabulary to articulate players' strategies. For example, Remote Impact supports a shared virtual space, but not a shared virtual body, as players cannot "move" their partner's avatar. They were rewarded for hitting the avatar, but the opponent's avatar did not move as a result of the hit. This impacted players' strategies: First, they dodged out of the way as they did not want to be hit. However, players soon realized that getting hit does not "move," and therefore hurt them, and hence does not hinder them in executing more hits (unlike in traditional boxing). As a consequence, players who started with more defensive tactics often changed to a more offensive approach.

Looking at the bodily interplay dimension also inspired us (Figure 11) to consider supporting a shared virtual body, where a player's actions would allow the opponent's avatar to be moved, for example through force-feedback technology. Alternatively, Remote Impact could support a shared virtual object, such as a virtual sandbag that both

<table>
<tr><th>Coupling</th><th>Physical space</th><th>Virtual space</th></tr>
<tr><td>Comparative Coupling</td><td>Knowing</td><td>Comparing</td></tr>
<tr><td colspan="3">In this variation of Remote Impact, players are co-located, hitting the same mattress; therefore they know when each other is exerting. The virtual space allows comparing this exertion investment by displaying the intensity of their hits through the projection on the mattress surface, resulting in a calibrating experience.</td></tr>
<tr><td>Actuated Coupling</td><td>Knowing</td><td>Shared object</td></tr>
<tr><td colspan="3">In this game, the co-located players hit the same mattress, therefore knowing when the other player is exerting. They have to hit the same moving target object projected onto the mattress, which functions as a shared object, making for a channeling experience.</td></tr>
<tr><td>Projected Coupling</td><td>Shared body</td><td>Shared body</td></tr>
<tr><td colspan="3">In this game, there is no mattress, but rather the players have to hit each other's bodies (shared body), which are augmented with projections that display impact areas virtually (shared body), making for a coordinating experience.</td></tr>
<tr><td>Derived Coupling</td><td>Shared body</td><td>Comparing</td></tr>
<tr><td colspan="3">In this derived coupling game, the players are again hitting each other's bodies (shared body), however, the goal is not who executes the most hits, but rather to achieve the lowest heart rate (comparing), making for a contributing experience.</td></tr>
</table>

Fig. 11. Using the bodily interplay dimension to extend Remote Impact.

participants need to hit. Designers could also move the game into the Comparative Coupling section by removing the shared aspect, for example by projecting two virtual sandbags, which offers an experience that is probably more akin to a training session in which athletes practice side-by-side.

11. EXAMPLE 4: KINECT ADVENTURE

We now also look at an existing commercial exertion game to demonstrate the benefit of our framework beyond our own games. Kinect Adventures [Wikipedia contributors 2015] is a well-known commercial game that is often sold with the Xbox game console. Kinect Adventure features a virtual wild river rafting game in which two players need to lean left and right to steer their avatars that stand together on a virtual raft going down a virtual wild river, trying to collaboratively circumnavigate rocks and other obstacles (Figure 12).

11.1. Bodily interplay in Kinect Adventures

11.1.1. Bodily Interplay in the Physical Space. The two players in Kinect Adventure are meant to stay approximately one meter apart as instructed at the start of the game. Accordingly, Kinect Adventures features parallel play in the physical space.

11.1.2. Bodily Interplay in the Virtual Space. The two players are represented as virtual avatars. These avatars do not act interdependently with one another; however, they

Fig. 12. Kinect Adventures.

control a shared virtual object: the raft. As such, Kinect Adventures features interdependent play in the virtual space.

11.1.3. Explaining and Extending Kinect Adventure Through the Design Space. Players are playing in parallel in the physical space. This is a consequence of the fact that the Kinect's motion sensing algorithms are optimized to detect individual non-overlapping bodies. In the virtual space, the players are sharing a virtual object, the raft: Only if both players are leaning left at the same time does the raft fully steer left. As such, the virtual object facilitates a social play experience through collaborative action in which players act on a shared object, with players needing to coordinate their leaning actions to circumnavigate larger obstacles. Due to this mix, Kinect Adventure is an Actuated Coupling game.

Kinect Adventure uses the characteristics of a shared object quite cleverly: First, it uses the object to enable an interdependent play experience even though the sensors are not optimized for interdependent play. Second, the characteristics of a shared object (in contrast to "shared space" or "shared body") allowed the designers to easily address limited accuracy capabilities of the Kinect sensor. For example, let us assume a player is leaning left, but the camera is not very precise so the raft is not steering left. This does not affect gameplay too much, as the second player also controls the raft, so the first player might simply assume that if the raft is not turning left, it is because of the other player. Furthermore, the water surrounding the raft might move it around unpredictably to a certain extent anyhow. So the first player might simple lean even more to the left until the sensor picks up the movement. As such, the shared

<table>
<tr><th>Coupling</th><th>Physical space</th><th>Virtual space</th></tr>
<tr><td>Comparative Coupling</td><td>Knowing</td><td>Comparing</td></tr>
<tr><td colspan="3">In this game, players are co-located, therefore they know they are exerting. The virtual space supports comparing by sensing when players lean; however, unlike in the current Kinect Adventures, each player has their own virtual space in a split screen arrangement, making for a calibrating experience.</td></tr>
<tr><td>Actuated Coupling</td><td>Knowing</td><td>Shared body</td></tr>
<tr><td colspan="3">In this game, the physical space arrangement is the same as in the original Kinect Adventures; however, players share an avatar by one player controlling the avatar's legs, the other player controlling the avatar's arms (shared body), making for a collaborative game with a channeling experience.</td></tr>
<tr><td>Projected Coupling</td><td>Shared body</td><td>Shared body</td></tr>
<tr><td colspan="3">In this game, the players hold a balancing pole together that is replicated in the virtual space (shared body) to navigate the river torrents, making for a coordinating experience.</td></tr>
<tr><td>Derived Coupling</td><td>Shared body</td><td>Comparing</td></tr>
<tr><td colspan="3">In this game, the players are sharing the balancing pole (shared body); however, the goal of the game is to collect as many jumps (over rocks in the virtual river) as possible (comparing), making for a contributing experience.</td></tr>
</table>

Fig. 13. Using the bodily interplay dimension to extend Kinect Adventure.

virtual object allowing for interdependent play helps the designers to support social play despite limited sensor abilities.

Looking at the dimension aids us envision design iterations (Figure 13). For example, we can imagine a version where players are encouraged to stick their hand out to "grab" their partner's avatar to pull them toward their side of the raft to circumnavigate very big obstacles. This would introduce the game to a "shared body" in the virtual space, and could even be extended to the physical space, where players would need to pull their co-players by their sweaters to their side. Such game tactics would move the game into the Projected Coupling section and might motivate sensor engineers to enhance the Kinect to detect "sweater-pulling."

12. DISCUSSION

We now discuss our contribution but also articulate the limitations of our findings and where we see future work.

The bodily interplay dimension has helped us in analyzing existing designs we have developed in our lab. By looking at the design space, we have been able to quickly determine where many existing games sit and where we could "move" them to in the design space to facilitate different player experiences. The design space has also helped us with inspiration for new designs, as certain areas of the design space are less populated than others and therefore offer new opportunities we are eager to explore. The dimension has also helped us to discuss our designs as it provided us with a vocabulary to articulate how our design ideas are different to existing work. We hope other designers and researchers can similarly benefit from our work.

We now discuss limitations. First, our findings are derived from our craft knowledge of designing social exertion games. As such, the strength of our work is its practice-based orientation in a design tradition that is tightly linked with technology implementation; however, such an approach has inherent limitations [Höök and Löwgren 2012]. For example, our framework might need updating once new technologies emerge. Furthermore, our framework's validation comes through our experiences of working with it supplemented by its application to Kinect Adventures to show its utility. However, we acknowledge that further validation, for example, through workshops with designers could be an avenue for future work.

Also, our work focuses on exertion games that feature a virtual space, in which exertion is represented. Recently, digital games have emerged that challenge the notion of what we conventionally assume is a virtual space. For example, JS Joust [Wilson 2012] facilitates body contact by putting players' movement representation "into their hands": Players carry the "screen" that represents their movements in the form of a Sony Move controller that lights up in reaction to physical movement. This game does not feature a screen in the traditional sense, yet our work is also useful in analyzing this game, for example it directs thinking about how bodily interdependence is facilitated by the representation of movement through a one-pixel screen in the form of an LED. Another similar game is Ubiquity [Williams et al. 2010]. For us, these games challenge the traditional role of digital representations in virtual spaces by blurring the distinction between physical space and virtual space. Nevertheless, the result is often bodily interdependence, suggesting that our dimension can also be a useful tool for these types of exertion games that sit on the blurry boundary between physical and virtual space.

Also, another limitation of our work is the focus on player–player interactions, leaving out any exertion interactions with non-players, such as spectators or non-human players like NPCs and bots (as hinted by Isbister [2010]). Although most interactions with spectators are depicted as being verbal, it seems plausible to argue that playing in front of thousands of spectators can result in a different bodily experience compared to playing alone. As such, investigating the exertion interactions between players and non-players could be another interesting avenue for future research.

13. CONCLUSION

Our work was motivated by the increased focus on exertion activity in human-computer interaction. Prior work suggests that exertion can facilitate, and benefit from, social play. However, there is only limited knowledge about designing for bodily interactions between players. We believe how bodies interact with one another is an underexplored area in games that offers unique opportunities. In response, we introduced the idea of the bodily interplay dimension that we instantiated in both the physical and virtual space in order to provide an initial structured understanding in regards to the many ways bodies can interact with one another in exertion games. Together, the instantiations cover four different areas of the design space of bodily interactions in exertion games. Exertion game designers can use the resulting framework to analyze existing games and explore alternative design possibilities. The framework also helps identify opportunities and challenges when supporting bodily interplay and guides designers as to what types of experiences their designs afford.

We have applied the bodily interplay dimension to four example games. For JoD, we used bodily interplay to understand the initial experience and compare it to non-augmented jogging. We then applied the dimension back to the design, which generated further ideas such as using a shared audio space to support the comparison of exertion.

For TTT, the dimension was used to explain the role of virtual bricks in facilitating offensive and defensive actions even though players are in geographically separate locations. Examining TTT's position in the design space led to new design ideas such as making movements in the videoconference part of the gameplay. For Remote Impact, the dimension helped explain players' tactical choices. Looking at Remote Impact's position in the design space also revealed new ideas for future versions of Remote Impact while still supporting interdependent play. We also applied the bodily interplay dimension to Kinect Adventures, which helped explain how social play can be facilitated, even with limited sensor capabilities, through the use of a shared virtual object.

Across all examples, the bodily interplay dimension helped us to be clearer about the unique opportunities when bodily activity and interactive technology converge and also to identify interaction design challenges. However, we also note that looking at bodily interactions between people does not mean that there is a guarantee for social play to occur. After all, it is the player that creates social play; the design can only support the emergence of such social play [Salen and Zimmerman 2003a]. Having said that, our framework allows for focused explorations and discussions on bodily aspects, which might be particularly useful when considering involved technologies and aiming to understand what interactions between players they afford.

We are intrigued by the possibility that focusing on mismatches between bodily interplay in the physical and virtual space can lead to new design opportunities and novel experiences and believe that this can be a useful design approach, as more and more bodily interactions will be mediated by technology in the future. With this in mind, we are particularly interested in applying the framework to emerging experiences that involve extreme bodily interactions in non-traditional areas, such as underwater and even outer space.

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REFERENCES

P. A. Andersen and K. Leibowitz. 1978. The development and nature of the construct touch avoidance. *Environmental Psychology and Nonverbal Behavior* 3, 2 (1978), 89–106.

J. N. Bailenson, J. Blascovich, A. C. Beall, and J. M. Loomis. 2003. Interpersonal distance in immersive virtual environments. *Personality and Social Psychology Bulletin* 29, 7 (2003), 819–833.

B. G. Behrenshausen. 2007. Toward a (kin) aesthetic of video gaming: The case of dance dance revolution. *Games and Culture* 2, 4 (2007), 335.

T. Bekker, J. Sturm, and B. Eggen. 2010. Designing playful interactions for social interaction and physical play. *Personal Ubiquitous Computing* 14, 5 (2010), 385–396.

S. Benford, J. Bowers, L. E. Fahlén, C. Greenhalgh, and D. Snowdon. 1995. User embodiment in collaborative virtual environments. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 242–249.

S. Benford, C. Brown, G. Reynard, and C. Greenhalgh. 1996. Shared spaces: Transportation, artificiality, and spatiality. In *Proceedings of the 1996 ACM Conference on Computer Supported Cooperative Work.* ACM, 77–86.

S. Benford, C. Greenhalgh, G. Reynard, C. Brown, and B. Koleva. 1998. Understanding and constructing shared spaces with mixed-reality boundaries. *ACM Transactions on Computer-Human Interaction (TOCHI)* 5, 3 (1998), 185–223.

S. Benford, C. Greenhalgh, G. Giannachi, B. Walker, J. Marshall, and T. Rodden. 2012. Uncomfortable interactions. In *Proceedings of the 2012 ACM Annual Conference on Human Factors in Computing Systems.* Austin, Texas, 2005–2014.

S. Benford, H. Schnädelbach, B. Koleva, R. Anastasi, C. Greenhalgh, and T. Rodden. 2005. Expected, sensed, and desired: A framework for designing sensing-based interaction. *ACM Transactions on Computer-Human Interaction (TOCHI)* 12, 1 (2005), 3–30.

P. Bernasconi and J. Kohl. 1993. Analysis of co-ordination between breathing and exercise rhythms in man. *The Journal of Physiology* 471, 1 (1993), 693.

I. Bogost. 2006. Persuasive Games: Wii's Revolution is in the Past. Retrieved from http://www.seriousgamessource.com/features/feature_112806_wii_1.php.

I. Bogost. 2007. Persuasive Games: The Missing Social Rituals of Exergames. Retrieved from http://seriousgamessource.com/features/feature_013107_exergaming_1.php.

C. F. Bond and L. J. Titus. 1983. Social facilitation: A meta-analysis of 241 studies. *Psychological Bulletin* 94, 2 (1983), 265–292.

J. E. Brand, P. Lorentz, and T. Mathew. 2014. Digital Australia 2014. Retrieved from http://www.igea.net/wp-content/uploads/2013/11/Digital-Australia-2014-DA14.pdf.

P. Broadhead. 2004. *Early Years Play and Learning: Developing Social Skills and Cooperation*. Psychology Press.

T. Campbell, B. Ngo, and J. Fogarty. 2008. Game design principles in everyday fitness applications. In *Proceedings of the 2008 ACM Conference on Computer Supported Cooperative Work*. San Diego, CA, 249–252.

A. D. Cheok, K. H. Goh, W. Liu, F. Farbiz, S. W. Fong, and S. L. Teo. 2004. Human Pacman: A mobile, wide-area entertainment system based on physical, social, and ubiquitous computing. *Personal and Ubiquitous Computing* 8, 2 (2004), 71–81.

E. E. A. Cohen, R. Ejsmond-Frey, N. Knight, and R. I. M. Dunbar. 2010. Rowers' high: Behavioural synchrony is correlated with elevated pain thresholds. *Biology Letters* 6, 1 (2010), 106.

Y. A. W. de Kort, and W. A. Ijsselsteijn. 2008. People, places, and play: Player experience in a socio-spatial context. *Computers in Entertainment (CIE)* 6, 2 July (2008), 18.

A. Doucette, C. Gutwin, R. Mandryk, M. Nacenta, and S. Sharma. 2013. Sometimes when we touch: How arm embodiments change reaching and collaboration on digital tables. In *Proceedings of the 2013 Conference on Computer Supported Cooperative Work.* ACM, 193–202.

P. Dourish. 2001a. *Where the Action is: The Foundations of Embodied Interaction*. MIT Press, Boston, MA.

P. Dourish. 2001b. *Where the Action is: The Foundations of Embodied Interaction*. MIT Press, Boston, MA, 167.

P. Dourish and S. Harrison. 1996. Re-placing space: The roles of place and space in collaborative systems. In *Proceedings of the 1996 ACM Conference on Computer Supported Cooperative Work*. ACM, 68–85.

N. Ducheneaut, N. Yee, E. Nickell, and R. J. Moore. 2006. Alone together?: Exploring the social dynamics of massively multiplayer online games. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.* ACM, 407–416.

G. S. Elias, R. Garfield, K. R. Gutschera, and P. Whitley. 2012a. *Characteristics of Games*. MIT Press, 37.

G. S. Elias, R. Garfield, K. R. Gutschera, and P. Whitley. 2012b. *Characteristics of Games*. MIT Press, Preface xiii.

G. S. Elias, R. Garfield, K. R. Gutschera, and P. Whitley. 2012c. *Characteristics of Games.* MIT Press, 38.

D. England, E. Hornecker, C. Roast, P. Romero, P. Fergus, and P. Marshall. 2009. Workshop on whole-body interactions. In *Proceedings of the 27th International Conference on Extended Abstracts Human Factors in Computing Systems (CHI'09).* Boston, MA, 1–4. Retrieved from http://lister.cms.livjm.ac.uk/homepage/staff/cmsdengl/WBI2009/.

Entertainment Software Association. 2015. Essential Facts About the Computer and Video Game Industry. Retrieved from http://www.theesa.com/wp-content/uploads/2015/04/ESA-Essential-Facts-2015.pdf.

Y. Fernaeus. 2012. *How Do You Design for The Joy Of Movement*? In Plei-Plei. PPP Company Ltd., 122–129.

Fitbit. 2012. Fitbit. Retrieved from http://fitbit.com.

M. H. Fogtmann. 2007. Kinesthetic empathy interaction – Exploring the possibilities of psychomotor abilities in interaction design. In *Proceedings of Workshop on Physicality*. 2–3 September 2007, Lancaster University, UK. Retrieved from http://www.interactivespaces.net/data/uploads/papers/18.pdf.

M. H. Fogtmann, J. Fritsch, and K. J. Kortbek. 2008. Kinesthetic interaction – revealing the bodily potential in interaction design. In *OZCHI'08 Proceedings of Conference of the Computer-Human Interaction Special Interest Group (CHISIG) of Australia on Computer-Human Interaction*. Cairns, Australia.

J. Frost, S. Wortham, and R. Reifel. 2008. Play and Child Development. Characteristics of Social Play. Retrieved from http://www.education.com/reference/article/characteristics-social-play/.

T. Fullerton, C. Swain, and S. Hoffman. 2004. *Game Design Workshop*. In Gama Network Series (2nd ed.: A Playcentric Approach to Creating Innovative Games ed. 54). Morgan Kaufmann.

B. Gajadhar, Y. de Kort, and W. IJsselsteijn. 2008. Influence of social setting on player experience of digital games. In *Proceedings of CHI'08 Extended Abstracts on Human Factors in Computing Systems*. Florence, Italy, 3099–3104.

L. Graves, G. Stratton, N. D. Ridgers, and N. T. Cable. 2007. Comparison of energy expenditure in adolescents when playing new generation and sedentary computer games: Cross sectional study. *BMJ* 335, 7633 (2007), 1282–1284.

C. Greenhalgh and S. Benford. 1995. Virtual reality tele-conferencing: Implementation and experience. In *Proceedings of the Fourth European Conference on Computer-Supported Cooperative Work (ECSCW'95)*. 165–180.

A. Guye-Vuillème, T. K. Capin, I. S. Pandzic, N. M. Thalmann, and D. Thalmann. 1999. Nonverbal communication interface for collaborative virtual environments. *Virtual Reality* 4, 1 (1999), 49–59.

M. Hagger and N. Chatzisarantis. 2005. *Social Psychology of Exercise and Sport*. Open University Press, Bershire, England, 177.

E. T. Hall. 1969. *The Hidden Dimension*. Anchor Books, New York.

P. Hämäläinen, T. Ilmonen, J. Höysniemi, M. Lindholm, and A. Nykänen. 2005. Martial arts in artificial reality. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.* ACM, Portland, Oregon, 781–790.

J. Hindmarsh, M. Fraser, C. Heath, S. Benford, and C. Greenhalgh. 1998. Fragmented interaction: Establishing mutual orientation in virtual environments. In *Proceedings of the 1998 ACM Conference on Computer Supported Cooperative Work.* ACM, 217–226.

M. Hobye and J. Löwgren. 2011. Touching a stranger: Designing for engaging experience in embodied interaction. *International Journal of Design* 5, 3 (2011), 31–48.

K. Höök and J. Löwgren. 2012. Strong concepts: Intermediate-level knowledge in interaction design research. *ACM Transactions on Computer-Human Interaction* 19, 3 (2012), 1–18.

A. Huggard, A. D. Mel, J. Garner, C. C. Toprak, A. Chatham, and F. Mueller. 2013. Musical embrace: Exploring social awkwardness in digital games. In *Proceedings of the 2013 ACM International Joint Conference on Pervasive and Ubiquitous Computing.* ACM, Zurich, Switzerland, 725–728.

C. Hummels, K. C. J. Overbeeke, and S. Klooster. 2007. Move to get moved: A search for methods, tools and knowledge to design for expressive and rich movement-based interaction. *Personal and Ubiquitous Computing* 11, 8 (2007), 677–690.

IAAF. 2012. IAAF Competition Rules 2012–2013. Retrieved from http://www.iaaf.net/mm/Document/06/28/26/ 62826_PDF_English.pdf.

K. Isbister. 2010. *Evaluating User Experience in Games.* In Enabling Social Play: A Framework for Design and Evaluation. R. Bernhaupt (Ed.). Springer, London, 11–22.

P. Jeffrey and G. Mark. 1999. *Social Navigation of Information Space*. Navigating the virtual landscape: Co-ordinating the shared use of space. Springer, 112–131.

G. Joost and F. Hemmert. 2010. In touch with representation: Iconic, indexical and symbolic signification in tangible user interfaces. In *Proceedings of Design Research Society Conference.* Montreal (Quebec), Canada. Retrieved from http://www.designresearchsociety.org/docs-procs/DRS2010/PDF/058.pdf.

J. Juul. 2005. *Half-real: Video Games Between Real Rules and Fictional Worlds*. MIT Press.

J. Juul. 2009. *A Casual Revolution: Reinventing Video Games and Their Players*. MIT Press, Boston, MA.

C. Karageorghis and D. L. Priest. 2008. Music in sport and exercise: An update on research and application. *The Sport Journal* 11, 3 (2008).

R. Koster. 2011. Social Mechanics for Social Games. Retrieved from http://www.raphkoster.com/wp-content/uploads/2011/02/Koster_Social_Social-mechanics_GDC2011.pdf.

L. Lanningham-Foster, T. B. Jensen, R. C. Foster, A. B. Redmond, B. A. Walker, D. Heinz, and J. A. Levine. 2006. Energy expenditure of sedentary screen time compared with active screen time for children. *Pediatrics* 118, 6 (2006), 1831–1835.

A. Larssen, L. Loke, T. Robertson, J. Edwards, and A. Sydney. 2004. Understanding movement as input for interaction—A study of two eyetoy games. In *Proceedings of OZCHI'04.* Wollongong, Australia.

J. Lehrer. 2006. How the Nintendo Wii Will Get You Emotionally Invested in Video Games. Seedmagazine.com. *Brain & Behavior*. Retrieved from http://www.seedmagazine.com/news/2006/11/a_console_to_make_you_wiip.php.

S. E. Lindley, J. Le Couteur, and N. L. Berthouze. 2008. Stirring up experience through movement in game play: Effects on engagement and social behaviour. In *Proceedings of the Twenty-sixth Annual SIGCHI Conference on Human Factors in Computing Systems*. ACM, Florence, Italy, 511–514.

L. Loke, A. Larssen, T. Robertson, and J. Edwards. 2007. Understanding movement for interaction design: Frameworks and approaches. *Personal and Ubiquitous Computing* 11, 8 (Special Issue Movement-Based Interaction) (2007), 691–701.

L. Loke and T. Robertson. 2013. Moving and making strange: An embodied approach to movement-based interaction design. *ACM Transactions on Computer-Human Interaction (TOCHI)* 20, 1 (2013), 7.

M. Ludvigsen, M. Fogtmann, and K. Gronbek. 2010. Tactowers: An interactive training equipment for elite athletes. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems (DIS'10).* Aarhus, Denmark, 412–415.

K. MacDonald. 2014. Motion-Controlled Gaming is Flailing. Retrieved from http://www.kotaku.com.au/2014/05/motion-controlled-video-games-are-over/.

R. Maddison, C. Mhurchu, A. Jull, Y. Jiang, H. Prapavessis, and A. Rodgers. 2007. Energy expended playing video console games: An opportunity to increase children's physical activity? *Pediatric Exercise Science* 19, 3 (2007), 334.

R. Mandryk, S. Atkins, and K. Inkpen. 2006. A continuous and objective evaluation of emotional experience with interactive play environments. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'06).* Montreal, Quebec, Canada, 1027–1036.

M. McElroy. 2002. *Resistance to Exercise: A Social Analysis of Inactivity*. Human Kinetics Publishers, Champaign, IL. Microsoft. 2010. Xbox Kinect. Retrieved from http://www.xbox.com/en-US/kinect.

J. Moen. 2006. *KinAesthetic Movement Interaction: Designing for the Pleasure of Motion*. Unpublished Dissertation. Stockholm, KTH, Numerical Analysis and Computer Science.

M. Montola, J. Stenros, and A. Waern. 2009. *Pervasive Games: Theory and Design*. Morgan Kaufmann, Burlington, MA.

F. Mueller, S. Agamanolis, M. Gibbs, and F. Vetere. 2009. Remote impact: Shadowboxing over a distance. In *Proceedings of the 27th International Conference of Extended Abstracts on Human Factors in Computing Systems (CHI'09).* Boston, MA, 3531–3532.

F. Mueller, S. Agamanolis, and R. Picard. 2003. Exertion interfaces: Sports over a distance for social bonding and fun. In *Proceedings of SIGCHI Conference On Human Factors In Computing Systems*. Ft. Lauderdale, Florida, 561–568.

F. Mueller, D. Edge, F. Vetere, M. R. Gibbs, S. Agamanolis, B. Bongers, and J. G. Sheridan. 2011. Designing sports: A framework for exertion games. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'11).* ACM, Vancouver, Canada, 2651–2660.

F. Mueller, M. Gibbs, and F. Vetere. 2008. Taxonomy of exertion games. In *Proceedings of the 20th Australasian Conference on Computer-Human Interaction (OZCHI'08)*. Cairns, Australia, 263–266.

F. Mueller, M. Gibbs, and F. Vetere. 2009. Design influence on social play in distributed exertion games. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'09)*. ACM, Boston, MA, 1539–1548.

F. Mueller, M. Gibbs, F. Vetere, S. Agamanolis, and D. Edge. 2014. Designing mediated combat play. In *Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction.* ACM, 149–156.

F. Mueller, S. O'Brien, and A. Thorogood. 2007. Jogging over a distance: Supporting a jogging together experience although being apart. In *Proceedings of Conference on Human Factors in Computing Systems (CHI'07).* ACM, 2579–2584.

F. Mueller, S. Stellmach, S. Greenberg, A. Dippon, S. Boll, and J. Garner. 2014. Proxemics play: Understanding proxemics for designing digital play experiences. In *Proceedings of the 2014 Conference on Designing Interactive Systems.* ACM, 533–542.

F. Mueller, F. Vetere, M. Gibbs, D. Edge, S. Agamanolis, J. Sheridan, and J. Heer. 2012. Balancing exertion experiences. In *Proceedings of SIGCHI Conference on Human Factors in Computing Systems.* ACM, 1853–1862.

F. Mueller, F. Vetere, M. R. Gibbs, S. Agamanolis, and J. Sheridan. 2010a. Jogging over a Distance: The influence of design in parallel exertion games. In *Sandbox'10 Proceedings of the 5th ACM SIGGRAPH Symposium on Video Games.* ACM, 63–68.

F. Mueller, F. Vetere, M. R. Gibbs, D. Edge, S. Agamanolis, and J. G. Sheridan. 2010b. Jogging over a distance between Europe and Australia. In *Proceedings of the 23rd Annual ACM Symposium on User Interface Software and Technology (UIST'10).* ACM, 189–198.

V. Nenonen, A. Lindblad, V. Häkkinen, T. Laitinen, M. Jouhtio, and P. Hämäläinen. 2007. Using heart rate to control an interactive game. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Zystems.* ACM, San Jose, California, 853–856.

Nike+. 2015. Retrieved from https://en.wikipedia.org/w/index.php?title=Nike%2B&oldid=695694167.

C. Nilsson. 2004. Computer-Supported Cooperative Work and Embodied Social Interaction. Unpublished Ph.D. thesis. University of Skövde, Sweden.

Nintendo. 2006. Wii. Retrieved from http://wii.nintendo.com.

M. Nitsche. 2009. *Video Game Spaces: Image, Play, and Structure in 3D Worlds*. The MIT Press, Boston, MA.

S. O'Brien and F. Mueller. 2007. Jogging the distance. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 523–526.

M. B. Parten. 1932. Social participation among pre-school children. *The Journal of Abnormal and Social Psychology* 27, 3 (1932), 243.

K. Rubin. 2001. The Play Observation Scale. Retrieved from http://www.rubin-lab.umd.edu/Coding Schemes/POS Coding Scheme 2001.pdf.

K. Salen and E. Zimmerman. 2003a. *Rules of Play: Game Design Fundamentals*. The MIT Press, Boston, MA.

K. Salen and E. Zimmerman. 2003b. *Rules of Play: Game Design Fundamentals*. The MIT Press, Boston, MA, 594.

T. Schiphorst, F. Nack, M. KauwATjoe, S. De Bakker, L. Aroyo, A. P. Rosillio, H. Schut, and N. Jaffe. 2007. Pillowtalk: Can we afford intimacy? In *Proceedings of the 1st International Conference on Tangible and Embedded Interaction*. ACM (2007), 23–30.

E. M. Segura, A. Waern, J. Moen, and C. Johansson. 2013. The design space of body games: Technological, physical, and social design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.* ACM, 3365–3374.

J. Sheridan, A. Dix, S. Lock, and A. Bayliss. 2005. Understanding interaction in ubiquitous guerrilla performances in playful arenas. In *Proceedings of People and Computers XVIII—Design for Life,* S. Fincher, P. Markopoulos, D. Moore, and R. Ruddle (Eds.). Springer, London, 3–17.

J. Sheridan and F. Mueller. 2010. Fostering kinesthetic literacy through exertion games. In *Proceedings of Workshop on Whole-Body Interactions at International Conference on Human Factors in Computing Systems (CHI'10).* Atlanta.

M. Slater and M. Usoh. 1994. Body centred interaction in immersive virtual environments. *Artificial Life and Virtual Reality* 1, (1994), 125–148.

Sony. 2010. Playstation Move. Retrieved from http://us.playstation.com/ps3/playstation-move/.

H. Strömberg, A. Väätänen, and V.-P. Räty. 2002. A group game played in interactive virtual space: Design and evaluation. In *Proceedings of the 4th Conference on Designing Interactive Systems*. ACM, 56–63.

Tacx. 2009. Tacx Virtual Reality. Retrieved from http://www.tacxvr.com.

A. Tang, M. Pahud, K. Inkpen, H. Benko, J. C. Tang, and B. Buxton. 2010. Three's company: Understanding communication channels in three-way distributed collaboration. In *Proceedings of the 2010 ACM Conference on Computer Supported Cooperative Work.* ACM, 271–280.

N. Triplett. 1898. The dynamogenic factors in pacemaking and competition. *The American Journal of Psychology* 9, 4 (1898), 507–533.

T. Tucker. 2006. Tetris Weightlifting. Retrieved from http://www.tetrisweightlifting.com/.

A. Voida, S. Carpendale, and S. Greenberg. 2010. The individual and the group in console gaming. In *Proceedings of the 2010 ACM Conference on Computer Supported Cooperative Work*. ACM, 371–380.

A. Voida and S. Greenberg. 2009. Wii all play: The console game as a computational meeting place. In *Proceedings of the 27th International Conference on Human Factors in Computing Systems.* ACM, 1559–1568.

J. von Zitzewitz, P. Wolf, V. Novakovic, M. Wellner, G. Rauter, A. Brunschweiler, and R. Riener. 2008. Real-time rowing simulator with multimodal feedback. *Sports Technology* 1, 6 (2008), 257–266.

D. P. Vossen. 2004. The nature and classification of games. *Avante* 10, 1 (2004), 53–68.

R. Wakkary, M. Hatala, Y. Jiang, M. Droumeva, and M. Hosseini. 2008. Making sense of group interaction in an ambient intelligent environment for physical play. In *Proceedings of the 2nd International Conference on Tangible and Embedded Interaction*. ACM, 179–186.

R. S. Weinberg and D. Gould. 2006. *Foundations of Sport and Exercise Psychology*. Human Kinetics, Champaign, IL.

Wikipedia Contributors. 2015. Kinect Adventures! Retrieved from http://en.wikipedia.org/w/index.php?title=Kinect_Adventures!&oldid=577747109.

Wikipedia Contributors. 2012. Kinect Sports. Retrieved from http://en.wikipedia.org/wiki/Kinect_Sports.

A. Williams, L. Hughes, and B. Simon. 2010. Propinquity: Exploring embodied gameplay. In *Proceedings of the 12th ACM International Conference Adjunct Papers on Ubiquitous Computing - Adjunct.* ACM, 387–388.

D. Wilson. 2012. *Designing for the Pleasures of Disputation -or- How to Make Friends by Trying to Kick Them*! Unpublished Dissertation, IT University of Copenhagen.

WirHabenFun. 2011. Wii FAIL Accidents. Retrieved from http://www.youtube.com/watch?v=VVUMMorJTC8.

J. Yim and T. C. N. Graham. 2007. Using games to increase exercise motivation. In *Proceedings of the 2007 Conference on Future Play.* ACM, 166–173.

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