Towards Balancing Fun and Exertion in Exergames

Exploring the Impact of Movement-Based Controller Devices, Exercise Concepts, Game Adaptivity and Player Modes on Player Experience and Training Intensity in Different Exergame Settings

Zur Erlangung des Grades eines Doktors der Naturwissenschaften (Dr. rer. nat.)
genehmigte Dissertation von Anna Lisa Martin-Niedecken (geb. Martin) aus Hadamar
Tag der Einreichung: 05.11.2020, Tag der Prüfung: 11.02.2021

1. Gutachten: Prof. Dr. rer. medic. Josef Wiemeyer
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TECHNISCHE UNIVERSITÄT DARMSTADT

Department of Human Sciences
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Darmstadt, den 05. November 2020

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Abstract

Physical inactivity remains one of the biggest societal challenges of the 21st century. The gaming industry and the fitness sector have responded to this alarming fact by introducing game-based or gamified training scenarios and thus established the promising trend of exergaming. Exergames – games controlled by active (whole) body movements – have been extolled as potential attractive and effective training tools. However, the majority of the exergames do not meet the required intensity or effectiveness, nor do they induce the intended training adherence or long-term motivation. One reason for this is that the evaluated exergames were often not co-designed with the user group to meet their specific needs and preferences, nor were they co-designed with an interdisciplinary expert team of game designers (to ensure a good gaming experience) and sports scientists (for a great training experience). Accordingly, the research results from studies with these exergames are rather limited.

To fully exploit the potential of these innovative movement tools and to establish them as attractive and effective training approach, it is necessary to understand and explore both the underlying interdisciplinary theories and concepts as well as possible design approaches and their impact on the game and training experience.
This dissertation aims to contribute to a better understanding of well-balanced exergame design. It explores and evaluates how different movement-based control devices, exercise concepts, game adaptations, and player modes influence the attractiveness and effectiveness of exergames. The work provides theoretical and practical contributions to the problem area of effective and attractive exergames. For this purpose, a research and development (R&D) approach with iterative phases was followed (Figure 1).

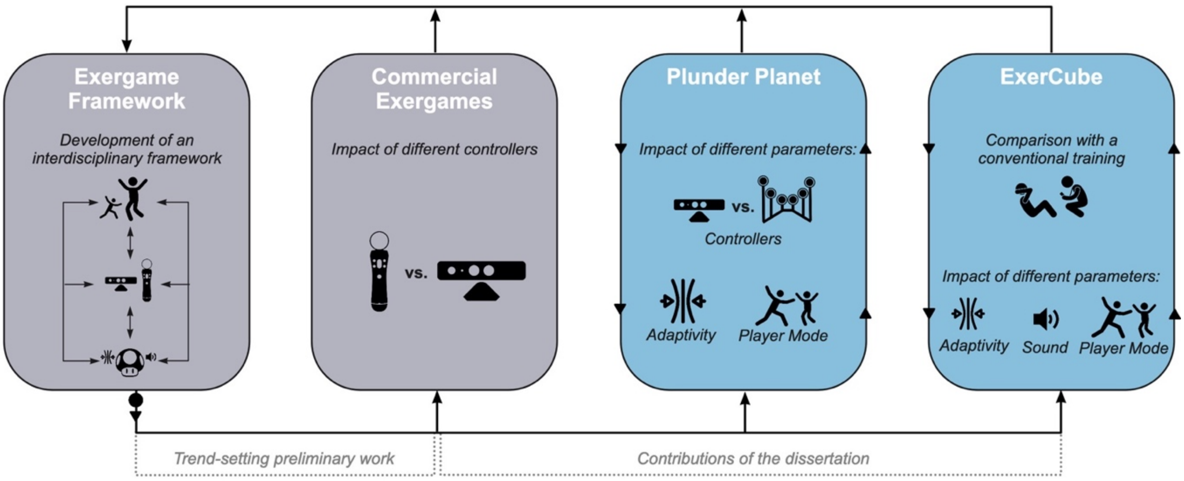

Figure 1: R&D process of the dissertation with iterative phases: Based on theoretical findings, an interdisciplinary framework model was developed in preliminary work. The findings from the first study phases were then transferred into explorative exergame designs, which in turn served to further investigate various parameters. The results provided indications for the further development and research of the exergames and the interdisciplinary framework model.

As preliminary work for the contributions of this dissertation, exergames were approached from a theoretical perspective. Underlying multidisciplinary theories and concepts of exergames from relevant fields were analyzed and a generic framework was built, which structured the findings based on three interdependent dimensions: the player, the game controller, and the virtual game scenario.
Some commercially available exergames were explored to verify the theory-based assumption that the interposition of technology brings specific transformations in the coupling of perception and action that do not occur in real sports situations. Among other things, the comparative pilot study showed that two different controllers (one gesture-based and one haptic device), which allowed for different physical

input, were likely to induce diverse gameplay experiences (e.g., higher feeling of flow and self-location when playing with the haptic device) with differently skilled players. However, certain design-specific differences in the two exergame conditions meant that these results could only be interpreted as a first trend.

To overcome the limitations of this preliminary study approach (e.g., unequal game design of the commercial exergames and very sports-specific movement concept), Plunder Planet, an adaptive exergame environment, was iteratively designed with and for children and allowed for a single- and cooperative multiplayer experience with two different controller devices. The user-centered design was further informed by insights from the growing body of related R&D work in the field of exergames.
The first study presented in this dissertation compared the subjectively experienced attractiveness and effectiveness of Plunder Planet when played with different motion-based controllers. Besides a generally great acceptance of the exergame, it was found that the haptic full-body motion controller provided physical guidance and a more cognitively and coordinatively challenging workout, which was more highly rated by experienced gamers with fewer athletic skills. The gesture-based Kinect sensor felt more natural, allowed more freedom of movement, and provided a rather physically intense but cognitively less challenging workout, which was more highly rated by athletic players with less gameplay experience. Furthermore, experiments were made with an exploratory adaptive algorithm that enabled the cognitive and the physical challenge of the exergame to be manually adapted in real-time based on the player's fitness and gaming skills.
The first and the second study also compared an adaptive with a non-adaptive single player version of Plunder Planet. It could be shown that the (well-balanced) adaptive version of the exergame was better valued than the non-adaptive version with regard to the experienced and measured attractiveness (motivation, game flow, spatial presence experience, balance of cognitive and physical challenge) and effectiveness (heart rate, physical exertion, balance of cognitive and physical challenge) by differently skilled players.
Finally, and contrary to the findings from related work, the results of the third study proved that the specifically designed controller technology could be used as an "enabler", "supporter" and "shaper" of bodily interplay in social exergaming.

Based on these promising findings, the goal became to further explore the effectiveness of exergames, refine the adaptive game difficulty algorithm, and explore further attractiveness- and motivation-boosting design approaches.
Therefore, the ExerCube, a physically immersive and adaptive fitness game setting, was developed. It was iteratively designed with and for adults and allowed for cooperatively and competitive exergame experiences. With its physically immersive game setup, the ExerCube combines a mixed version of the advantages of both previously tested controllers. A coordinatively and cognitively challenging functional workout protocol with scalable intensity (moderate to high) was developed and the subjective experience of the ExerCube training was compared with a conventional functional training with a personal trainer. The fourth study showed that the game-based training gave signs of reaching a similar intensity to the personal training, but was more highly rated for flow, motivation, and enjoyment. Based on this exploratory comparison of the ExerCube with a personal trainer session, valuable avenues for further design could be identified. Among other things, it could be proved that the player's focus during the ExerCube session was more on the game than on the own body. Players experienced stronger physical exertion and social pressure with the personal trainer and a stronger cognitive exertion and involvement with the ExerCube.
Furthermore, a refined version of the previously tested adaptive game difficulty algorithm was implemented and automated for the first time for purpose of this study. Again it was shown that the adaptive version had benefits with regard to subjectively experienced attractiveness (motivation, game flow, balance of cognitive and physical challenge) and effectiveness (physical exertion, balance of cognitive and physical challenge) compared to the non-adaptive version. In order to further enhance the gaming experience, experiments were also conducted with sound designs and an adaptive audio design

with adaptive background music and sound feedback was implemented. It was found to be a promising and beneficial add-on for a user-centered attractive exergame design.
To inform the design of a multiplayer version of the ExerCube, different social play mechanics were explored in the fifth study. This resulted in differently balanced experiences of fun, and in physical as well as cognitive exertion.
As the preliminary comparative evaluation of the subjectively experienced effectiveness and attractiveness of an ExerCube session and a personal trainer session could prove the general feasibility of the concept and revealed the first indications of the intensity of the ExerCube's training concept, the objectively measured effectiveness of a single ExerCube session with a functional high-intensity interval training (fHIIT) with a personal trainer was compared in a final sixth study, and after another design iteration. Again, the subjectively experienced attractiveness of both conditions was assessed. It could be shown that the ExerCube is a feasible training device for training at fHIIT-level. While physical exertion was slightly lower than in the conventional fHIIT condition, the ExerCube condition's average heart rate values reached the fHIIT threshold and also yielded significantly better results for flow, enjoyment, and motivation. The ExerCube training also resulted in a subjectively experienced higher cognitive load (dual-domain training).

To sum up, it can be stated that this dissertation provides valuable and fundamental research contributions to the promising field of exergames as attractive and effective training tools. Furthermore, important contributions to design questions in this field could be developed. Since this field is still relatively unexplored, the work presented creates a sound basis for future R&D work in this area.

Zusammenfassung

Bewegungsmangel ist nach wie vor eine der größten gesellschaftlichen Herausforderungen des 21. Jahrhunderts. Die Spieleindustrie und die Fitnessbranche haben auf diese alarmierende Tatsache mit der Einführung spielbasierter oder gamifizierter Trainingsszenarien reagiert und damit den vielversprechenden Trend des Exergamings etabliert. Exergames – Spiele, die durch aktive (Ganz-) Körperbewegungen gesteuert werden – wurden als potenziell attraktive und effektive Trainingswerkzeuge angepriesen. Allerdings erreicht die Mehrzahl der Exergames weder die geforderte Intensität oder Effektivität, noch induzieren sie die beabsichtigte Trainingsadhärenz oder Langzeitmotivation. Ein Grund dafür ist, dass die evaluierten Exergames oftmals weder unter Berücksichtigung spezieller Anforderungen und Präferenzen der jeweiligen Zielgruppen entwickelt noch mit dieser co-designt wurden. Ebenfalls wurde häufig nicht mit einem interdisziplinären Expertenteam bestehend aus Game Designerinnen und Designern (für ein gutes Spielerlebnis) sowie Sportwissenschaftlerinnen und -wissenschaftlern (für ein gutes Trainingserlebnis) zusammengearbeitet. Die Forschungsergebnisse aus Studien mit diesen Exergames sind dementsprechend limitiert.

Um das Potenzial dieser innovativen Trainingsgeräte voll auszuschöpfen und sie als attraktiven und effektiven Trainingsansatz zu etablieren, ist es notwendig sowohl die zugrundeliegenden interdisziplinären Theorien und Konzepte als auch mögliche Designansätze und deren Auswirkungen auf die Spiel- und Trainingserfahrung zu verstehen und zu erforschen.
Diese Dissertation soll zu einem besseren Verständnis von gut ausbalanciertem Exergame-Design beitragen. Sie exploriert und evaluiert, wie unterschiedliche bewegungsbasierte Steuerungsgeräte, Bewegungskonzepte, Spieladaptionen und Spielermodi die Attraktivität und Effektivität von Exergames beeinflussen. Die Arbeit liefert theoretische und praktische Beiträge zum Problemfeld effektiver und attraktiver Exergames. Dazu wurde ein Forschungs- und Entwicklungsansatz (F&E) mit iterativen Phasen verfolgt (Abbildung 1).

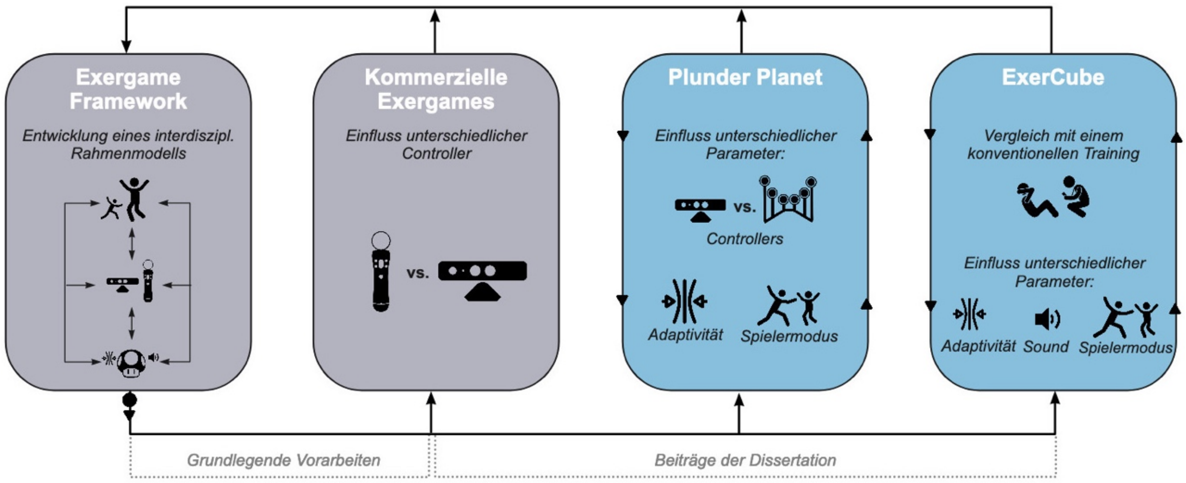

Abbildung 1: F&E-Prozess der Dissertation mit iterativen Phasen: Basierend auf theoretischen Erkenntnissen wurde in Vorarbeiten ein interdisziplinäres Rahmenmodell entwickelt. Die Erkenntnisse aus ersten Studienphasen wurden anschließend in explorative Exergame-Designs überführt, die wiederum zur weiterführenden Beforschung verschiedener Parameter dienten. Die Ergebnisse lieferten jeweils Indikationen, die in die Weiterentwicklung und -beforschung der Exergames und des interdisziplinären Rahmenmodells einflossen.

Als Vorarbeit für die Beiträge dieser Dissertation wurden Exergames zunächst aus einer theoretischen Perspektive betrachtet. Die grundlegenden multidisziplinären Theorien und Konzepte aus relevanten Bereichen wurden analysiert und ein generisches Rahmenmodell entwickelt, das die gewonnenen Erkenntnisse anhand von drei voneinander abhängigen Dimensionen gliederte: dem Spieler bzw. der Spielerin, dem Spielcontroller und dem virtuellen Spielszenario.

Anschließend wurden kommerziell erhältliche Exergames untersucht, um die theoriegeleitete Annahme zu prüfen, dass die Interposition von Technologie spezifische Transformationen in der Kopplung von Wahrnehmung und Handlung hervorruft, die in realen Sportsituationen nicht existieren. Die vergleichende Pilotstudie konnte unter anderem zeigen, dass zwei verschiedene Controller (ein gestenbasiertes und ein haptisches Gerät), die jeweils andere physische Bewegungseingaben ermöglichten, unterschiedliche Spielerfahrungen (z.B. ein besseres Flow- und Selbstverortungserlebnis mit der haptischen Steuerung) bei Spielerinnen und Spielern mit unterschiedlichen Fähigkeiten induzierten. Aufgrund designspezifischer Unterschiede in den beiden Exergame-Bedingungen konnten diese Ergebnisse jedoch nur als ein erster Trend interpretiert werden.

Um bestehende Limitationen des vorangegangenen Studienansatzes zu überwinden (z.B. das ungleiche Spieldesign der kommerziellen Exergames und ein sehr sportartspezifisches Bewegungskonzept), wurde Plunder Planet konzipiert, eine adaptive Exergame-Umgebung, die iterativ mit und für Kinder entwickelt wurde und ein Einzel- sowie kooperatives Mehrspielererlebnis mit zwei verschiedenen Controller-Geräten ermöglichte. Das nutzerzentrierte Design wurde zudem basierend auf Erkenntnissen aus der wachsenden Zahl thematisch relevanter F&E-Arbeiten erweitert.
Die erste Studie dieser Dissertation verglich die subjektiv erlebte Attraktivität und Effektivität von Plunder Planet beim Spielen mit verschiedenen bewegungsbasierten Controllern. Neben einer allgemein großen Akzeptanz des Exergames konnte festgestellt werden, dass die haptische Ganzkörperbewegungssteuerung eine physische Orientierung sowie ein kognitiv und koordinativ herausforderndes Training bot, das von erfahrenen Spielerinnen und Spielern mit geringer ausgeprägten sportlichen Fähigkeiten besser bewertet wurde. Der gestenbasierte Kinect-Sensor fühlte sich hingegen natürlicher an, erlaubte eine höhere Bewegungsfreiheit und bot ein körperlich intensiveres, aber kognitiv weniger herausforderndes Training, das von sportlichen Spielerinnen und Spielern mit weniger Spielerfahrung besser bewertet wurde. Darüber hinaus wurde mit einem explorativen adaptiven Algorithmus experimentiert, der es ermöglichte, die kognitive und physische Herausforderung des Exergames in Echtzeit und auf Grundlage der Fitness und Spielfähigkeiten der Spielerinnen und Spieler manuell anzupassen.
Die erste und die zweite Studie verglichen außerdem eine adaptive mit einer nicht-adaptiven Einzelspielerversion von Plunder Planet. Es konnte gezeigt werden, dass eine (gut ausbalancierte) adaptive Version des Exergames hinsichtlich der subjektiv erlebten Attraktivität (Motivation, Spielfluss, räumliche Präsenzerfahrung, Balance zwischen kognitiver und physischer Herausforderung) und Effektivität (körperliche Anstrengung, Balance zwischen kognitiver und physischer Herausforderung) von unterschiedlichen Spielertypen besser bewertet wurde als die nicht-adaptive Version.
Schließlich konnte entgegen der Erkenntnisse anderer Arbeiten in der dritten Studie gezeigt werden, dass die speziell entwickelte Controller-Technologie als „Enabler", „Supporter" und „Shaper" des körperlichen Zusammenspiels beim sozialen Exergaming eingesetzt werden kann.

Basierend auf diesen Erkenntnissen war nachfolgend das Ziel, die Effektivität von Exergames weiter zu explorieren, den Algorithmus für adaptive Spielschwierigkeiten zu optimieren und weitere attraktivitäts- und motivationsfördernde Designansätze zu erforschen. Dazu wurde der ExerCube entwickelt, eine physisch-immersive und adaptive Fitnessspielumgebung, die iterativ mit und für Erwachsene konzipiert wurde und sowohl kooperative als auch kompetitive Exergame-Erlebnisse ermöglichte.
Mit seiner physisch-immersiven Spielumgebung kombiniert der ExerCube verschiedene Vorteile der beiden zuvor getesteten Controller-Technologien. In der vierten Studie wurde ein koordinativ und kognitiv herausforderndes, funktionelles Trainingsprotokoll mit skalierbarer Intensität (moderate bis hohe Intensität) entwickelt und das subjektive ExerCube-Erlebnis mit einem funktionellen Intervalltraining mit einem Personal Trainer verglichen. Die Machbarkeit des spielbasierten Trainings konnte belegt werden und Indizien auf eine vergleichbare Intensität wie beim Personal Training sowie bessere Bewertungen des Flows, der Motivation und des Vergnügens gefunden werden. Auf der Grundlage des Vergleichs des ExerCubes mit einer Personal Trainer-Einheit konnten darüber hinaus wertvolle Anknüpfungspunkte für weiterführende Designs identifiziert werden. Unter anderem konnte

nachgewiesen werden, dass der Fokus der Spielerinnen und Spieler während des ExerCube-Trainings stärker auf das Spiel als auf den eigenen Körper gerichtet war. Die Spielerinnen und Spieler erlebten eine intensivere körperliche Anstrengung und sozialen Druck mit dem Personal Trainer sowie eine stärkere kognitive Anstrengung und Involvierung mit dem ExerCube.
Darüber hinaus wurde eine optimierte Version des bereits zuvor getesteten Algorithmus für adaptive Spielschwierigkeiten implementiert und für diese Studie erstmalig automatisiert. Wiederholt konnte nachgewiesen werden, dass die adaptive Version im Vergleich zur nicht-adaptiven Version Vorteile bezüglich der subjektiv erlebten Attraktivität (Motivation, Spielfluss, Gleichgewicht zwischen kognitiver und körperlicher Herausforderung) und Effektivität (körperliche Anstrengung, Gleichgewicht zwischen kognitiver und körperlicher Herausforderung) hatte. Um das Spielerlebnis weiter auszubauen wurden außerdem Experimente mit spezifischen Sound Designs durchgeführt und ein adaptives Audio-Design samt adaptiver Hintergrundmusik und Sound-Feedback implementiert. Dies erwies sich als vielversprechender und vorteilhafter Zusatz für ein nutzerzentriertes, attraktives Exergame-Design.
Anschließend wurden in der fünften Studie verschiedene soziale Spielmechanismen exploriert, um so das Design einer Mehrspielerversion des ExerCubes zu inspirieren. Diese resultierten in unterschiedlich ausgewogenen Erlebnissen von Spaß und körperlicher sowie kognitiver Anstrengung bei den Probanden.
Da die vorangegangene vergleichende Studie der subjektiv empfundenen Effektivität und Attraktivität einer ExerCube-Session mit einer Personal Trainer-Einheit die generelle Durchführbarkeit des Konzepts nachweisen konnte und erste Hinweise einer vergleichbaren Intensität des ExerCube-Trainingskonzepts gefunden wurden, wurde nach einer weiteren Design-Iteration in einer abschließenden sechsten Studie die objektiv gemessene Effektivität einer ExerCube-Session mit der einer einzelnen Session eines funktionellen, hochintensiven Intervalltrainings (fHIIT) mit einem Personal Trainer verglichen. Dabei wurde zusätzlich wieder die subjektiv empfundene Attraktivität beider Bedingungen evaluiert. Es konnte gezeigt werden, dass der ExerCube ein praktikables Trainingsgerät für ein Training auf fHIIT-Niveau ist. Während die körperliche Anstrengung etwas geringer war als bei der konventionellen fHIIT-Einheit, erreichten die durchschnittlichen Herzfrequenzwerte in der ExerCube-Session die fHIIT-Schwelle und führte verglichen zur Personal Trainer-Session zu signifikant besseren Ergebnissen für Flow, Vergnügen und Motivation. Das ExerCube-Training führte zudem zu einer subjektiv erlebten, höheren kognitiven Belastung (Dual-Domain-Training).

Zusammenfassend lässt sich festhalten, dass diese Dissertation wertvolle und grundlegende Forschungsbeiträge zum vielversprechenden Feld der Exergames als attraktive und effektive Trainingsinstrumente liefert. Darüber hinaus konnten wichtige Beiträge zu Designfragen in diesem Gebiet erarbeitet werden. Da dieses Gebiet noch weitestgehend unerforscht ist, schafft die vorliegende Arbeit eine solide Grundlage für zukünftige F&E-Arbeiten in diesem Bereich.

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1 Introduction and Motivation

Numerous guidelines emphasize the urgent need for regular physical activity to maintain a physically and mentally healthy lifestyle at all ages. According to the American College of Sports Medicine (ACSM), a regular exercise program includes cardiorespiratory, resistance, flexibility, and neuromotor training in addition to the activities of daily living to improve and maintain physical fitness and health is essential for most adults (Graber et al., 2011). However, surveys of the World Health Organization (WHO) continuously reveal that physical inactivity remains the greatest public health problem of the 21st century (Trost et al., 2014) and is one of the leading risk factors for chronic diseases and death worldwide. Besides a lack of motivation and time, changing behavioral and environmental factors (e.g., urbanization, mechanization, increased motorized transport) and a number of common exercise barriers (e.g., low self-esteem, no exercise partner, etc.) are the main reasons for this persisting problem (Trost et al., 2002). The COVID-19 pandemic and the resulting restrictions in public life have recently further limited opportunities to remain physically active (Pinto et al., 2020).
Therefore, stakeholders from various sectors have called for new attractive and effective training alternatives to reduce entry barriers and help to initiate and maintain training adherence for a wide range of people (e.g., Marshall and Linehan, 2020).

Along with the discouraging data on physical inactivity, worldwide surveys report an increasing number of people who consume games for many hours per week and on a frequent basis year by year: In 2020, the world population is about 7.8 billion (Weeks, 2020), of whom 33% are gamers (Gough, 2019), while only 19% of all adolescents and 73% of all adults are sufficiently physically active (World Health Organization, 2020). These facts point the way towards the potential that lies in game-based solutions when it comes to finding new ways to motivate people to engage in regular physical activity of a certain intensity and variety.

Exergames

Exergames, which require physical effort and are controlled by (full-body) movements (Oh and Yang, 2011), have been promoted as potential suitable tools to provide attractive and thus motivating and effective training alternatives or supplements by interdisciplinary research and development (R&D) communities. Exergames, which are also known as movement-based games (Mueller and Isbister, 2014), active video games (Biddiss and Irwin, 2010) or exertion games (Mueller et al., 2016), can be played in different single and multiplayer-settings and are used in different application areas (Figure 1).

Figure. 1: Overview of exemplary exergames and potential application areas and target groups (left: exergame home workout for adults (Nintendo, Ring Fit Adventure); middle: gamified group fitness class for seniors (Prama, Pavigym); right: game-based pediatric movement rehabilitation (Hocoma, Lokomat)).

Typically, a player who physically interacts with a motion-based controller technology moves in front of a screen that displays a virtual game scenario. This way, commercially available exergame platforms

such as the Nintendo Wii, the Sony Move or the Microsoft Kinect and their corresponding games have provided playful workout experiences for the living room for about 10 years now (e.g., Mueller et al., 2016; Martin-Niedecken & Mekler, 2018) and are currently experiencing a comeback (e.g., Ring Fit Adventure (Fig. 1, left)) for the Nintendo Switch console (Totilo, 2019).
Besides virtual exergame environments, exergame scenarios, which are similar to traditional sports games, can be played both indoors and outdoors with optional technical aids (e.g., Prama Pavigym featuring interactive floor concepts (Fig. 1, middle)) and thus completely dispense with the classic player-screen setting (e.g., Segura et al., 2013).
Apart from the entertainment market, game-based training and therapy applications (e.g. virtually augmented climbing (Kajastila & Hämäläinen, 2014), game-based, robot-assisted movement therapy (e.g., Martin et al. 2015 (Fig. 1, right)) or functional high-intensity interval exergaming (e.g., Martin-Niedecken et al., 2019)) continue to establish themselves in the fitness and rehabilitation sector.

Attractiveness and Effectiveness of Exergames

So far, more than 10 years of interdisciplinary R&D work have untapped the potential of exergames to be effective (physical outcomes) and attractive (compelling gameplay) tools for promoting physical activity and training in different target populations.

According to Sinclair et al. (2009) the key to a successful exergame is a well-balanced level of fun and exertion or respectively attractiveness and effectiveness – the dual flow.
The attractiveness of an exergame is the factor that motivates players to play, and to continue to play the game (short- and long-term). Among other things, it is reflected by a great (game) flow and gameplay experience, fun and enjoyment which, in principle, are reached if the player's skills match the challenge provided by the game (short- and long-term), and if the player likes the design (visuals, audio, game mechanics, game play, game controller and player mode) of the exergame. The effectiveness of an exergame is the factor which is ideally represented by measurable physiological and behavioral effects such as a better fitness level (e.g., endurance, strength, speed, coordination, etc.) and which is achieved if the player's fitness skills match the exergame's physical challenge, which is ideally based on a real training concept.
Attractiveness and effectiveness can be subjectively experienced and measured with specific qualitative and quantitative assessment tools (e.g., interviews or surveys), while the effectiveness of an exergame can further be objectively measured (e.g., physiological parameters such as heart rate) (see also Table 1).

Indications for Effectiveness of Exergaming

Studies in the field of exergaming have investigated various effects of commercially available and specifically developed exergames in different target populations such as children, adolescents, seniors or patients. Results provide some evidence for potential effects on the cognitive level (e.g., executive functions, attention, and visual-spatial skills: Benzing et al., 2016; Best, 2015; Mura et al., 2017; Staiano & Calvert, 2011; Stojan & Voelcker-Rehage, 2019; Xiong et al., 2019), the physical level (e.g., energy expenditure, heart rate, and physical activity: Best, 2015; Kari, 2017; Staiano and Calvert, 2011; Sween et al., 2014), and the mental level (e.g., social interaction, self-esteem, motivation, and mood: Byrne & Kim, 2019; Joronen et al., 2017; Lee et al., 2017; Li et al., 2016; Staiano & Calvert, 2011). Generally, exergames are well known for their playful combination of physically and cognitively challenging tasks and thus provide dual-domain training, which appears to be more effective than traditional training approaches (Ballesteros et al., 2018; Egger et al., 2019; Schättin et al., 2016; Stojan & Voelcker-Rehage, 2019).

Indications for Attractiveness of Exergaming

Besides the cognitive, physical and mental effectiveness of exergame training, it is also known for its appealing and motivating potential, especially in physically less active populations (e.g., Kappen et al., 2019; Lu et al., 2013). By offering different players with different motivational types (Tondello et al., 2019) an appealing audio-visual, narrative-based immersive game scenario, exergames can enable a shift of the player's (cognitive) focus to the playful experience, making it easier to engage in a physically challenging training (Martin-Niedecken et al., 2019). So far, exergames have successfully been shown to have the potential to increase training adherence (e.g., Valenzuela et al., 2018), long-term motivation (e.g., MacRae & Robertson, 2013), engagement (e.g., Lyons, 2015), immersion (e.g., Lu et al., 2013), and flow experience (e.g., Martin-Niedecken & Götz, 2017) in players from different populations.

Weak Points of Exergames

However, it was also often concluded that the majority of the evaluated exergames do not meet the required training intensity (Marshall & Linehan, 2020), nor lead to the intended training adherence or long-term motivation (Adam & Senner, 2016). This is possibly because these exergames were not necessarily specifically designed for the purpose of obtaining certain training results or to be used as a sustainable and motivating alternative to traditional training devices and methods. Another reason might be that they had not been developed in an interdisciplinary, iterative and participatory co-design process with the primary and secondary user group, as well as experts from the field of game design as well as movement and training science (Regal et al., 2020).
Simultaneously, interdisciplinary R&D work shed light on the interdependent main components of an exergame (body, controller and game scenario). Studies revealed insights on the impact of single and multiple components as well as of sub-components (e.g., player mode, adaptivity, other design parameters) on the attractiveness and effectiveness of exergames (e.g., Bianchi-Berthouze et al., 2007; Skalski et al. 2011; Stach & Graham, 2011). However, these findings were not necessarily considered holistically and in relation to each other (e.g., Martin-Niedecken, 2018).
These deficits need to be overcome by further R&D work to exploit the full potential of exergames and establish them as attractive and effective alternative or additional training tool.

Research Question and Main Foci

In order to be able to explore the topic of exergames extensively, it is necessary to understand the underlying theories and concepts of exergames, as well as the interdependent multi-level design of such movement-based games. Therefore, this dissertation combines both theoretical and applied R&D work to approach this complex issue from different perspectives.

The overall research question (**RQ**) of this thesis is:

- **RQ: How do different motion-based control devices, exercise concepts, game adaptations and player modes influence the attractiveness and effectiveness of exergames?**

To answer this RQ, this thesis aims to explore the following main foci (**F**):

- **F1:** Exploring the underlying, interdisciplinary **theories and concepts** of exergames

- **F2:** Exploring interdisciplinary, user-centered **exergame design and evaluation methods**

- **F3:** Exploring the impact of different exergame **controller technologies** and **input movements** on player experience (attractiveness) and exergame intensity (effectiveness)

- **F4:** Exploring the impact of **adaptive versus non-adaptive** exergame designs on player experience (attractiveness) and exergame intensity (effectiveness)

- **F5:** Exploring how different **player modes** influence player experience (attractiveness) and exergame intensity (effectiveness) in exergames

- **F6: Comparing** player experience (attractiveness) and intensity (effectiveness) of an adaptive exergame **with a conventional training** approach

Overview of Dissertation

The fundamental concepts and theories of related disciplines which were discussed in the theoretical preliminary work of this dissertation (Martin & Wiemeyer, 2012a/b) are continuously extended with recent topics that have appeared over the years in Manuscripts I to VI. Existing R&D gaps are identified and strategically approached in the further work. Next, the concepts and findings from related work are used to explore new design approaches and to develop two exergame setups – one for children (Manuscript I to III) and one for adults (Manuscript IV to VI) – and to perform different studies to verify the intended (subjectively experienced) attractiveness and (subjectively experienced and objectively measured) effectiveness of the respective exergames (Manuscript I to VI).

Table 1 provides a detailed overview of all evaluation methods used to assess the attractiveness and effectiveness of the tested exergames in the dissertation.

Table 1: Overview of evaluation methods used in the studies of the dissertation. A detailed description of each method including all relevant references can be found in the respective method section of the Manuscripts.

Category of Methods	Assessment of Attractiveness	Assessment of Effectiveness
Quantitative	• Game Experience Questionnaire **(GEQ)** • Kids Game Experience Questionnaire **(KidsGEQ)** • Spatial Experience Questionnaire **(SPES)** • Social Presence Experience Questionnaire **(SPGQ)** • Game Flow Questionnaire **(GFQ)** • Flow Short Scale **(FSS)** • Situational Motivation Scale **(SIMS)** • Physical Activity Enjoyment Scale **(PACES)** • Sound Design Experience **(SQ)** • Add. Dimensions: Enjoyment, Dual Flow, etc. **(AD)**	• Heart rate **(HR)** • Borg Scale: Perceived physical exertion **(BS_{Phy})** • Borg Scale: Perceived cognitive exertion **(BS_{Cog})** • In-game Performance **(IGP)**
Qualitative	• Guideline-based, semi-structured interviews **(I)** • (Participatory) observation **(PO)** • Video analysis **(VA)**	• (Participatory) observation **(PO)** • Video analysis **(VA)**

Table 2 provides an overview of all Manuscripts of the thesis including the exergames, which were of interest for the respective work, the presented main foci, the scientific contributions, and the (mixed) methods used to assess the attractiveness and effectiveness.

Table 2: Overview of all Manuscripts (main (in black), and secondary (in grey) foci, main scientific contributions and assessment tools) of the dissertation.

Manuscript	Exergame & Target Group	Main & Secondary Foci	Main Scientific Contributions	Assessment of Attractiveness	Assessment of Effectiveness
M I	**Plunder Planet** Co-designed with and for children Research-based iterations	F1 F2 F3 F4	• **Comparing** the impact of **2 controllers** (haptic vs. gesture-based) on **gameplay and spatial presence experience** with the user-centered, adaptive single player version of Plunder Planet	SPES KidsGEQ	HR (exploratory) IGP
M II		F1 F2 F3 F4	• **Comparing** the impact of **2 controllers** (haptic vs. gesture-based) on **gameplay and spatial presence experience** with **adaptive vs. non-adaptive single player version** of Plunder Planet • Testing the **feasibility of** the newly developed **design guideline for Dual Flow**	GFQ AD	HR (exploratory) IGP I
M III		F1 F2 F3 F5	• **Comparing** the impact of **2 controllers** (haptic vs. gesture-based) on **gameplay and social presence experience** with **adaptive single vs. multiplayer version** of Plunder Planet	SPGQ KidsGEQ PO	–
M IV	**ExerCube** Co-designed with and for adults Research-based iterations	F1 F2 F3 F4 F6	• **Comparing** the **subjective experience** of the **adaptive vs. non-adaptive** single player ExerCube with a **conventional functional workout** with a personal trainer • Exploring the impact of **adaptive sound** on **gameplay and training experience**	FSS GFQ AD SD	I VA HR (exploratory)
M V		F1 F2 F3 F5	• Exploring the **subjective experience of attractiveness and effectiveness** of real-time implementations of new socially immersive rules & variations in the **multiplayer ExerCube** • Exploring the **method "Embodied Sketching"** (Research through Design)	I VA PO	I VA
M VI		F1 F2 F3 F4 F6	• **Comparing** the objectively measured and subjectively reported **effectiveness and attractiveness** of a functional HIIT with the **adaptive** single player **ExerCube** and a **conventional functional HIIT**	FSS SIMS PACES GFQ AD	HR IGP BS_{Phy} BS_{Cog}

2 Overview

The R&D work presented in this dissertation, was preceded by a phase of fundamental preliminary work, which provided an important basis for the contributions of this thesis. Following, the main contributions of the previous work are briefly summarized:

Martin and Wiemeyer (2012a) opened up the theoretical and conceptual field of tension in motion-based gaming and presented first explorations of commercially available exergames based on a preliminary generic framework (Figure 2). They provided an overview of relevant concepts (e.g., game experience, (game) flow, and spatial presence experience), theories (e.g., inter- and intra-sensory integration or gestalt theory) and preliminary findings in related fields of exergames such as HCI, the psychology of perception, and gameplay experience research.
Based on these foundations, different interactions and interdependencies between the moving and sensing player, the mediating game controller technology and the virtual and physical game space were described. The core assumption was that the interposition of technology brings about specific transformations in the coupling of perception and action that do not occur in real sports situations. Furthermore, a preliminary pilot study put forward some theoretically based interview guidelines that were developed based on the previously discussed concepts, theories and findings from related work. These guidelines were then applied in an exploratory study setting, where participants played the dance game “Dance Central” with the gesture-based full-body motion game controller Kinect by Microsoft for Xbox 360 (Figure 3). Participants each performed two dance sessions with the exergame. The aim of this pilot study was to explore the controller’s impact on the players’ gameplay experiences and spatial presence experiences. This was particularly interesting, since full-body motion controllers were new on the market at the time of this study and there was not much knowledge concerning this topic, and even less concerning exergames. Furthermore, the integration of the player’s whole moving and exercising body into the gameplay and the resulting impact on the player’s gameplay experience were largely unexplored. Therefore, this explorative work provided a first, albeit preliminary (due to the very small sample size and a rather preliminary selection of related theories) dive into this promising new field of exergaming.

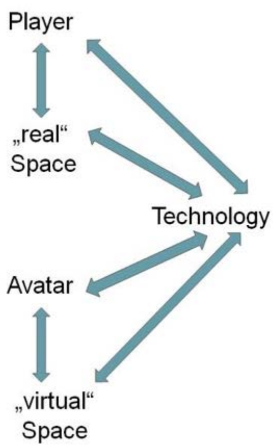

Figure 2: Generic Framework

Figure 3: Dance Central tutorial and performance.

Following the introduction of a theoretical framework, providing an overview of relevant concepts, theories and previous findings in related fields, and presenting preliminary findings of an exploratory evaluation of a dance exergame, Martin and Wiemeyer (2012b) ran another pilot study which took one

step further and focused on comparing the impact of different full-body motion controller games and the spatial presence experience.
Because at the time the first exploratory pilot study presented in the previously described work was performed there were no comparable dance games for different motion-controllers available, and also to establish whether the sports-specific design (dancing) of the exergames used had an additional influence on player's spatial presence and gameplay experience, Martin and Wiemeyer (2012b) conducted a similar study with commercially available volleyball exergames. Participants played volleyball games of "Sports Champions Beach Volleyball" on the PS3 with the Sony Move controller (Figure 4, left) and "Kinect Sports Volleyball" on the Xbox 360 with the gesture-based Kinect sensor (Figure 4, right).

Figure 4: Playing two volleyball exergames with the PS3 Sony Move sensor (left, Source: Sony) and the Xbox 360 Microsoft Kinect sensor (right, Source: Microsoft).

Between and after the sessions, participants completed two questionnaires that assessed the player's game flow and spatial presence experience. The pilot study revealed a higher degree of flow and self-location when playing with the haptic Move controller. This result seems to be caused by the low degree of control in the Xbox volleyball game, as well as the potentially missing haptic feedback. The sensor technology did not recognize movements correctly and this led to interruptions of the game flow. The findings for the experience of possible actions support this explanation. Because the interface was not the only difference between the two consoles, other reasons such as graphics, perspectives, sound, session and avatar may further explain the results. Hence, the results could not clearly confirm the expectation that different game interfaces alone elicit different gameplay and spatial presence experiences. Furthermore, it was only a pilot study with a relatively small sample size. Therefore, further research and development work was needed.
These preliminary findings laid the foundation for the R&D work presented in this dissertation.

This dissertation contains six Manuscripts. All Manuscripts are published articles. Information on each publisher and the original publication can be found at each chapter's cover page. Each Manuscript contains its own summary of references. The following paragraphs summarize the content of each manuscript and illustrate the relationships between the publications.

Manuscript I: Design and Evaluation of a Dynamically Adaptive Fitness Game Environment for Children and Young Adolescents

The preliminary work presented by Martin and Wiemeyer (2012a/b) provided an overview of relevant theories and concepts. Both exploratory pilot studies further helped to identify existing gaps in interdisciplinary exergame research and blind spots of commercially available exergame designs, which needed to be addressed to provide a beneficial, reliable and comparable basis for further exergame user studies.

Since both pilot studies revealed among other things that spatial presence and flow experience might be closely related to the individual's previous experience with and preference for the respective gamified sports (dancing or volleyball), the aim was to go further with more general and unspecific exergames.

Regarding the feeling of game flow and the generally experienced attractiveness and effectiveness of exergames, first theory-based concepts and evidence on adaptive exergames and dynamic game balancing in exergames appeared (Sinclair et al., 2007; Sinclair et al., 2009; Sinclair et al., 2010).
A promising approach to increasing exergame effectiveness and attractiveness is the personalization through system adaptations (Hardy et al., 2015), which is also known as dynamic game balancing (Altimira et al., 2016; Mueller et al., 2012), game difficulty adjustment (Adams, 2010) or multiplayer game balancing (Gerling et al., 2014). Besides various pre-exergaming and real-time in-exergaming adaption parameters such as game speed, frequency of in-game tasks and increasing intensity and range of the input-movement, in-exergame adaptations based on the player's heart rate (HR) have been proposed and explored by various researchers and designers and have been proved to be a feasible and beneficial approach to balance player's abilities and the exergame challenge (Hoffmann et al., 2015; Ketcheson et al., 2015; Mueller et al., 2012; Stach et al., 2015).
Based on these findings, a specific adaptive algorithm to balance various players' skills and the exergame requirements was created. Therefore, both the cognitive and the physical load and skills were taken into account, which allowed for manual dynamic and independent adjustments of both layers.

Besides this promising approach, the user-centered design of exergames was found to be missing from commercially available exergames, although designing for specific needs (e.g., training goals) and preferences (e.g., audio-visual look and feel) of different user groups (e.g., primary: children who play the exergame, secondary: trainer who uses the exergame as training tool for the training in children) was found to be promising for attracting, motivating and sustaining training adherence as well as long-term training effects, and for establishing exergames as supplementary or alternative training tools.

Furthermore, at the time of the work presented in Manuscript I, there were some new related studies available that provided further insights into the impact of different full-body motion controllers and the impact of the player's involved moving and exercising body on their exergame experience and thus informed the design of such motion-based game controllers. Among other things, it was found that the perceived "naturalness" of game controller interactions shapes the sense of spatial presence (Skalski et al. 2011). Further research showed that the type of interface feedback affects the gameplay experience: haptics matching on-screen actions improved immersion and enjoyment (Stach & Graham, 2011). It was also highlighted that the types of interface devices used for controlling the games, and the involvement of the entire human body in the gameplay are important variables in the emotional experiences of exergames (Vara et al., 2016) and an embodied interface was found to make the exergame experience more realistic and enjoyable (Kim et al., 2014).

Since there were no such exergames available, an adaptive and user-centered exergame was co-designed with and for children and developed based on results of interdisciplinary game research, as well as on first explorations of adaptive exergame n concepts for children (Martin & Kluckner, 2014). “Plunder Planet”, a coordinatively and cognitively challenging exergame setup, can be played with two controllers: a full-body motion controller (Figure 5, left), which provides the player with physical guidance and haptic feedback, while demanding coordinative and cognitive skills, and the gesture-based Kinect sensor, which allows greater freedom of movement (Figure 5, right). The game also features a trainer interface that allows for manually and independently adjusting the physical (based on the player’s HR) and cognitive (performance-related) load of the exergame to the skills and needs of the player in real-time.

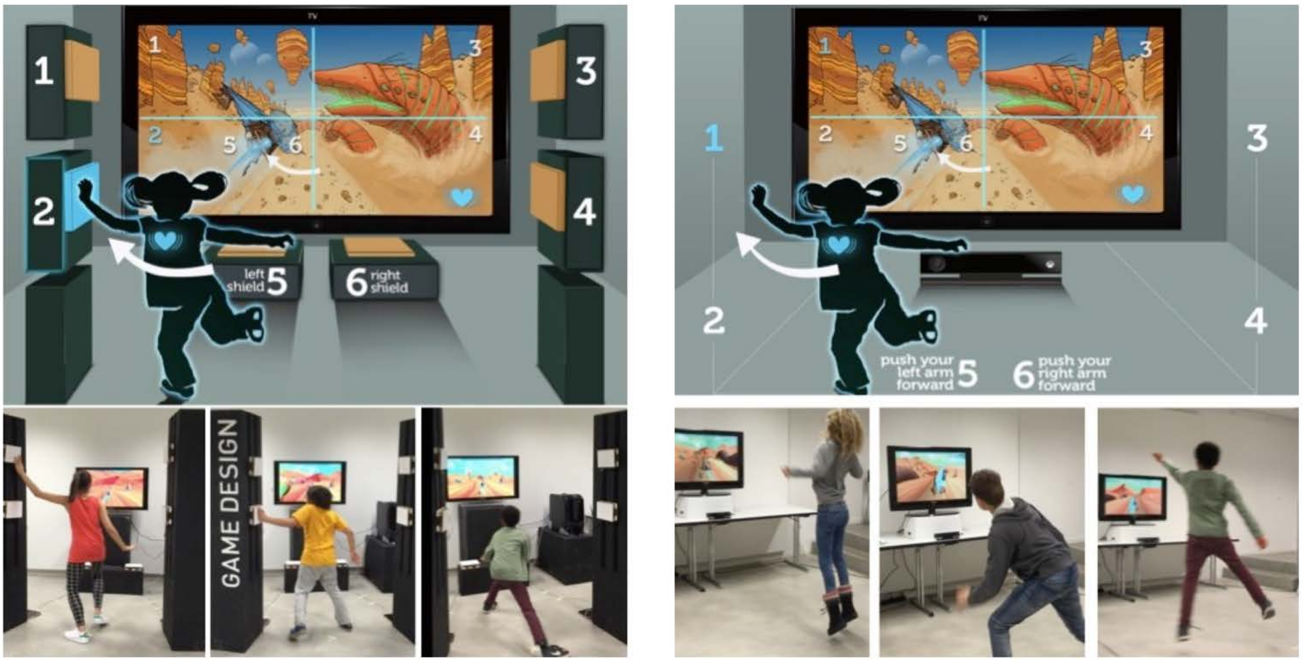

Figure 5: Earlier stage prototype of two motion-based controller setups (left: full-body motion controller; right: Kinect) of the adaptive exergame Plunder Planet.

A feasibility study with the Plunder Planet prototype investigated the fundamental functionality and usability of the system. Furthermore, participants’ game experiences and spatial presence experiences when playing with the different controller technologies were compared. Again, both subjectively experienced states were assessed with questionnaires. The results were analyzed with a secondary focus on participants’ previous gaming and sports experience.

It was found that athletic participants enjoyed the freedom and naturalness of movements of the Kinect sensor and experienced more flow, while non-athletic participants preferred the physical guidance and playfulness of the haptic full-body motion controller and reported higher feelings of flow with this controller version.
Furthermore, a preliminary exploration of the training intensity of Plunder Planet was conducted. After four play sessions (2x Kinect sensor and 2x full-body motion controller), each participant had been physically active for 40 minutes. The average HR was between 125-145 beats per minute (bpm) for the full-body motion controller and 130-160 bpm for the Kinect® setup. Thus, participants worked out within the “fat burning zone” (60-70% of HR_{max}) and the “aerobic zone” (70-80% of HR_{max}). Since this was only a preliminary exploration of the effectiveness, further studies were needed to be able to make a reliable statement about the effectiveness.

The R&D work presented in Manuscript I helped to deepen the knowledge from the previous pilot studies while reducing limitations (comparability) and confirming the effects of different controllers on the player's gameplay and spatial presence experience.
Furthermore, Plunder Planet was one of the first dynamically adaptive exergames and it laid the foundation for further novel R&D work in the field of attractive and effective exergames.

Manuscript II: Go with the Dual Flow: Evaluating the Psychophysiological Adaptive Fitness Game Environment "Plunder Planet"

After the feasibility study presented in Manuscript I and another manuscript, which is not part of this thesis (Martin-Niedecken, 2017) had successfully proved the impact of two different full-body motion controllers on the spatial and game experience of children playing the adaptive exergame Plunder Planet, Manuscript II focuses on exploring and verifying potential benefits of the adaptive version compared to the non-adaptive version of Plunder Planet (Figure 6) in an between-subjects study design. Additionally, the impact on gameplay experiences caused by playing both versions with two different controller devices was investigated.

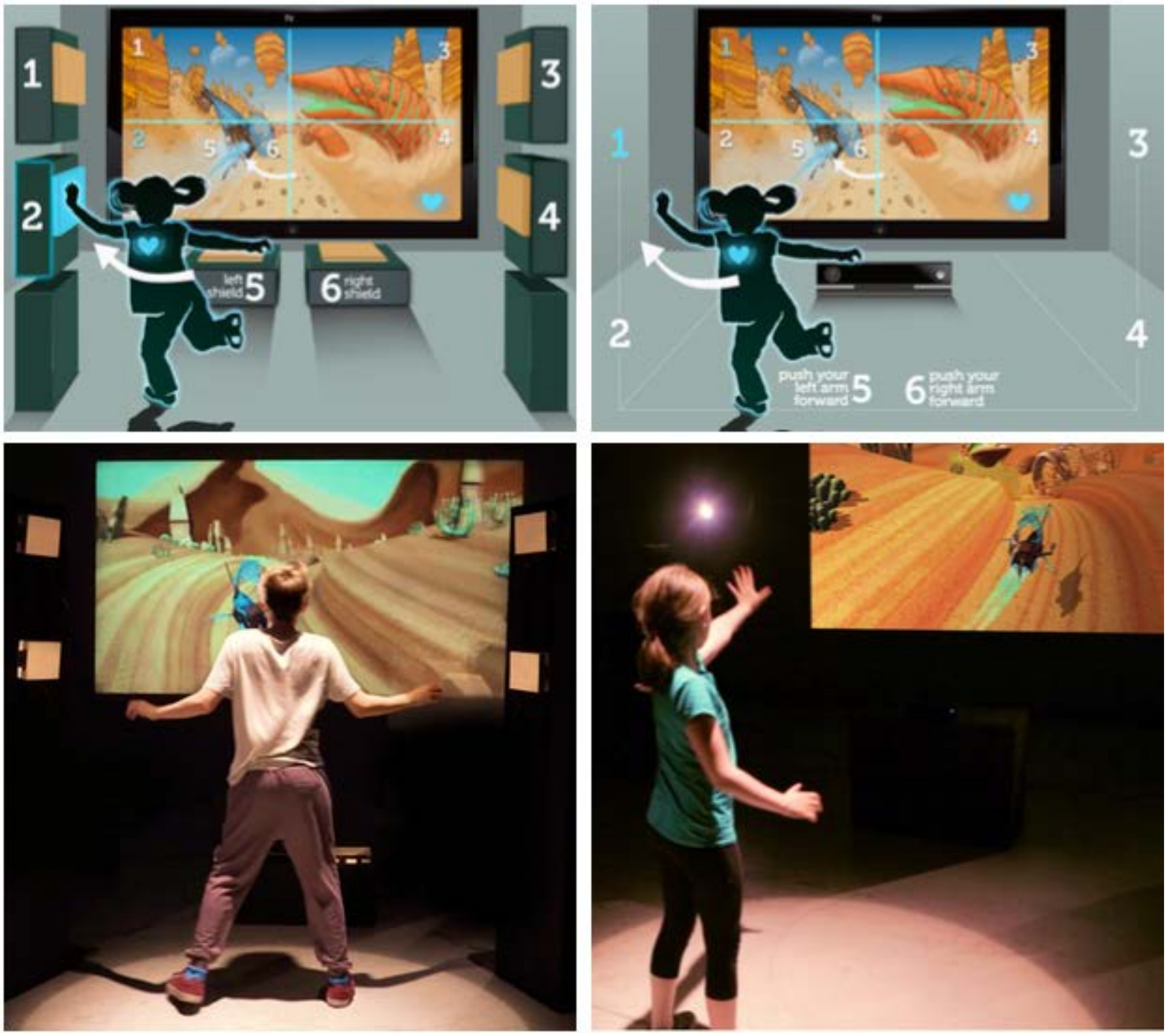

Figure 6: Prototypical state of two motion-based controller setups (left: full-body motion controller; right: Kinect) of the adaptive exergame Plunder Planet.

Therefore, children with more or less gaming and sports experience playing were assigned either to the Kinect- or the full-body motion controller group. After a familiarization phase, which served as pre-classification phase of the individual dual flow-range of each participant, all participants played two sessions (one adaptive and one non-adaptive) in a randomized order, and in their assigned controller-condition. The subjectively experienced game flow, dual flow, motivation, enjoyment, and spatial presence of participants playing the adaptive and the non-adaptive versions either with the Kinect or the full-body motion controller were evaluated via questionnaires. Furthermore, the respective training intensity was captured based on in-game performance and HR values, which were recorded throughout the exergame sessions. Again, the results were also analyzed with a secondary focus on participants' previous gaming and sports experience.

The advanced study presented in Manuscript II showed that the adaptive version held (highly) significant benefits compared to the non-adaptive version, and could thus confirm and extend then existing knowledge from findings of related work (Hoffmann et al., 2015; Stach et al., 2009). Results further confirmed the controller design decisions, including the positive impact of haptic feedback and physical guidance on the player's game flow experience and enjoyment.
Furthermore, a detailed guide for the pre-classification and maintenance of the individual dual flow level was introduced and tested, which was the result of the previously presented explorations and refinements of the physical-cognitive exergame adaption algorithm, and which could inform future R&D work in attractive and effective exergames.
Average HR values in both cases result from three "Plunder Planet" sessions (twelve minutes) and fall within the "fat burning zone" (60–70% of HR_{max}).

Some limitations of the presented work are that the comparative study was neither set up as a within-subjects design, nor were multiple training sessions included, and the primary focus was again mainly on the subjectively experienced attractiveness while the effectiveness was only examined rudimentarily. However, the work presented in Manuscript II rounds off the exploration of controller-dependent spatial presence experience in exergames. It further informs future R&D work in the field of attractive and effective exergames.

Manuscript III: Designing for Bodily Interplay: Engaging with the Adaptive Social Exertion Game "Plunder Planet"

Based on the single player game design and evaluation work presented in Manuscript I and II, Manuscript III opens up another R&D domain in exergames – the multiplayer mode. The presented work contributes to the much discussed debate on the existing gap in the design and research knowledge on social play in exergames.

Both on the commercial market and in the academic exergame field, numerous multiplayer exergames can be found, which approach the topic of social play in various ways (e.g., Gerling et al., 2014). However, most of the existing multiplayer exergames only allow players to interact independently and side by side without directly sharing a common gameplay experience (Mueller et al. 2017). Full-body motion game controller technology, which was not sufficiently body-designed and user-centered, is very often criticized as being the reason for these limitations. It is often implied that technology in (multiplayer) exergames "instrumentalizes" the body too much (Höök et al., 2016), that it narrows the possibilities of movement and limits or even eliminates social dynamics instead of "enabling", "supporting" of "shaping" them (Marquez Segura et al., 2013; Benford et al., 2005; Loke et al., 2007). Consequently, there is only limited knowledge regarding the structures and dynamics of bodily interactions in social play as well as on how to design for them.

Building on this knowledge, Manuscript III shows how different controller technologies can be used as social presence experience "shapers" by overcoming certain limitations in the bodily interactions presented by related controller devices on the market and how they can allow intensive and multi-level bodily interplay at the same time. Therefore, the single player version of Plunder Planet was further developed to be playable as co-located multiplayer version with both controller devices – the full-body motion controller and the Kinect (Figure 7). The design extension was inspired by related R&D work on social exertion games (Mueller et al., 2017), as well as observations that were made during public exhibitions of the exergame setup.

Figure 7: Single (upper left & right) and cooperative multiplayer version (lower left & right) of Plunder Planet with different motion-based controller setups.

In a study, the gameplay experiences of children when playing the single or the multiplayer version of Plunder Planet with the two different controllers was compared. Furthermore, the social presence experience with the multiplayer version was evaluated. Game and social presence experience were assessed via questionnaires. Additionally, the multiplayer exergame sessions were observed following a pre-defined guideline to obtain further insights into the players' bodily interplay and social exertion play strategies. Again, the results were also analyzed with a secondary focus on participants' previous gaming and sports experience.

For the single player version, findings from previous studies presented in Manuscript I and II could be confirmed. Game experience and game flow with the exergame were strongly related to previous experiences in sports and gaming. The Kinect was slightly preferred by athletic participants while the full-body motion controller received better ratings from non-athletic and/or gaming-experienced participants.

When it came to social presence experience, the full-body motion controller was better valued than the gesture-based Kinect. The feeling of "empathy" was greater, there were less "negative feelings" and more "engagement" with the full-body motion controller version. These results were further emphasized by the findings of the participatory observation which found that participants tended to be more interactive on the levels of interdependent bodily interplay and communication with the full-body motion controller version.

Besides the different impact of the two controller versions on players' social presence experience and their ability to serve as a social exertion "enabler" (to allow, empower, facilitate players to physically play together; e.g. by connecting players), "supporter" (to help, assist, encourage players to play together; e.g., by balancing different skills), and "shaper" (to create, guide, modify unique social exertion experiences; e.g. by evoking special team dynamics, communication, and bodily interplay), both devices were found to generate slightly different experiences, as well as bodily interplay and communication strategies, which were further enhanced by players' individual gaming and sports skills and preferences.

However, these first indications need further in-depth explorations to prove their validity and to derive more generalizable findings. Still, these results helped to identify design approaches for future social exertion games.

Manuscript IV: ExerCube vs. Personal Trainer: Evaluating a Holistic, Immersive, and Adaptive Fitness Game Setup

Following the confirmation of the "shaping" property of different motion-based controllers, the verification of the benefits of adaptive versus non-adaptive exergame designs and proof of the HR-based and performance-related adaption algorithm (presented in Manuscript I to III), further R&D gaps in exergame R&D were explored.

Thus, another user-centered and adaptive exergame setup for another, more heterogenous target audience (adults aged 16–50 years) was developed, with a specific focus on a state-of-the-art training concept to be suitable as a training tool in the fitness market, again following an iterative and interdisciplinary design process.

Experience-wise, certain benefits were found regarding flow, immersion and – in the multiplayer version of Plunder Planet – social presence with a haptic and physically guiding full-body motion controller (higher flow and spatial presence experience) for relatively untrained participants, and with a gesture-based controller allowing a greater freedom and naturalness of body movements for athletic participants in the R&D work presented in Manuscripts I to III. Therefore, the aim was to create a haptic, physically immersive controller-device that allowed for extremely free and natural-feeling functional workout movements. Functional workout movements are closely related to daily-life activities, which helps the naturalness of the input movements even more.
Effectivity-wise, Plunder Planet was found to provide an exergame workout at a HR range of around 125–145bpm with the full-body motion controller and 130–160bpm with the Kinect. Therefore, a controller setup that still allowed a playful and immersive experience, but higher and more scalable training intensities (from moderate to high intensity) was explored. Furthermore, a new "on-body" tracking system was tested to allow for more accurate movement recording and feedback loops.

The iterative and user-centered co-design process of the early-stage prototype of the ExerCube – an immersive, physically and cognitively challenging and adaptive functional fitness game setup, as well as a feasibility study with the early-stage prototype were presented in a separate manuscript (Martin-Niedecken & Mekler, 2018) which is not part of this dissertation, but served as basis for the work presented in Manuscript IV.

In this previously conducted feasibility study (Martin-Niedecken & Mekler, 2018) the players' flow, game flow, dual flow, enjoyment, motivation and experience of physical and cognitive challenge were assessed via questionnaires. Additionally, guideline-based interviews were conducted to inform the further design process on all relevant dimensions (player's bodily and exercising input movements, material and functionality of the controller, and the audio-visual and narrative appearance of the game scenario).
The findings show that the preliminary ExerCube prototype was usable and well received by the target audience. Even though the prototype was not fully playable and did not provide a completely designed game and training experience, the majority of the participants enjoyed the experience and felt immersed in the virtual world. Participants' feedback on the interview questions further helped to identify relevant design gaps and avenues for the implementation of dual flow-based game mechanics, the optimization of the training concept and hardware, as well as for the further development of the game scenario. Based on the findings, the ExerCube was further iterated and optimized.

Based on the R&D work presented in Manuscripts I to III as well as the work presented by Martin-Niedecken and Mekler (2018), Manuscript IV presents the further research-based development of the ExerCube. The findings from the study with the early-stage prototype of the ExerCube (Martin-Niedecken & Mekler, 2018), as well as field research at public exhibitions and a specific search for state-of-the-art training concepts, informed these revisions and iterations.

At the time the presented work was conducted, there was no related work available on exergame-based functional training with scalable intensity (moderate to high intensity), even though this is a very promising training approach (Buckley et al., 2015; Kliszczewicz et al., 2019; McRae et al., 2012; Menz et al., 2019).
Furthermore, the feasibility study (Martin-Niedecken & Mekler, 2018) only the very early-stage prototype of the ExerCube was tested, which neither included a fully exploited functional workout concept nor a fully user-centered designed, interactive game scenario including the implementation of the previously presented HR-based and performance-related adaption algorithm. Hence, both were further developed in another iteration and evaluated in a study. The aim was to explore the subjectively experienced effectiveness and attractiveness of the ExerCube training and to gain some early indications as to whether it was possible to reach the targeted intensity with the implemented training concept and the refined physical-cognitive exergame adaption algorithm, which, in addition to the still possible manual adaptation, was first automated in the work presented in Manuscript IV. To allow for a training on and around a pre-defined HR value, and to be close to the actual training practices on the market, a targeted HR range was implemented and certain in-game training progress levels and in-game tutorials were defined, which gradually guided the player through the training (from a warm-up to the peak of the training).

Another topic of particular interest with the R&D work presented in Manuscript IV was the implementation and exploration of (adaptive) sound in exergames.

So far, there was no exergame study available that compared the experience of an exergame-based training with a one-on-one workout with a personal trainer (the supreme discipline of workout guidance) to reveal insights to inform the next iteration of the ExerCube. Therefore, a user study was conducted that compared a functional training in the ExerCube to a functional training with a personal trainer (Figure 8). The study design allowed for a specific focus on participants' subjective experience of the attractiveness and effectiveness of both trainings and for a further exploration of the adaptive algorithm by comparing the adaptive versus the non-adaptive version of the ExerCube as a secondary focus.
The same methods were used as in the previous feasibility study (Martin-Niedecken & Mekler, 2018) to assess flow, game flow, dual flow, motivation, enjoyment, immersion, cognitive and physical challenge. Furthermore, the players' audio experience was assessed via a specifically developed questionnaire. Additionally, semi-structured interviews were conducted and all training sessions in the ExerCube and with the personal trainer were video-recorded.

To address the need for more realistic and therefore field-related comparisons between exergames and conventional sports (Marshall and Linehan, 2020), participants' multi-sensory and bodily experiences with a non-adaptive and an adaptive ExerCube version were evaluated and compared with personal training to reveal insights to inform the next iteration of the ExerCube.

Figure 8: The functional workout with the ExerCube vs. a one-on-one training with a personal trainer.

Although the ExerCube was still work-in-progress at the time of the study, the mixed-methods analysis revealed that with regard to flow, enjoyment, and motivation, the adaptive ExerCube was on a par with the personal trainer. This finding once more proved the feasibility and beneficial impact of the physical-cognitive adaption algorithm for the experienced attractiveness of the exergame.
Furthermore, differences were found in participants' experience of the three main design aspects (body, controller, and game scenario). Particularly their perception of exertion, types and quality of movement, social factors, feedback, and audio experiences varied in the conditions. These findings were used to derive practical recommendations for future exergame developments and to further develop the ExerCube.

For the purpose of the R&D work presented in Manuscript IV, the focus was not on an in-depth analysis of the players' HR values. An exploratory check of the log files of the ExerCube sessions however revealed promising values with a range from 131bpm during the warm-up to 194bpm in the peak of the workout. Therefore, the evaluation of the objectively measured effectiveness of a functional training in the ExerCube was limited to the subjectively experienced effectiveness (and attractiveness) of a single session with all conditions. However, it was still a promising avenue for further research.

Manuscript V: Towards Socially Immersive Fitness Games: An Exploratory Evaluation Through Embodied Sketching

Manuscript IV presented the design and exploratory evaluation of the single-player version of the ExerCube. Since the overall aim was to design the ExerCube for a wide range of people, the aim of the R&D work presented in Manuscript V was to build on the previous experience in designing for bodily interplay with Plunder Planet (Manuscript III), as well as on the fact that social play and cooperative and competitive workouts are a big trend in today's gaming and fitness market, and to design and explore a socially immersive, attractive, and effective version of the ExerCube.

So far, there was a gap in related R&D work focusing on attractive and effective multiplayer exergames, as well as on related design methodologies. To contribute to this topic, an embodied sketching activity with co-located cooperative and competitive multiplayer variations of the ExerCube game scenario was conducted (Figure 9), which allowed testing of new physical and social game mechanics. This research through design method was applied with participant-pairs, who each played for about 25 minutes (2x 10min cooperative and 1x 5min competitive) and experienced 18–21 competitive and cooperative game variations. All sessions were video-recorded and concluded by a guideline-based semi-structured interview with the teams.

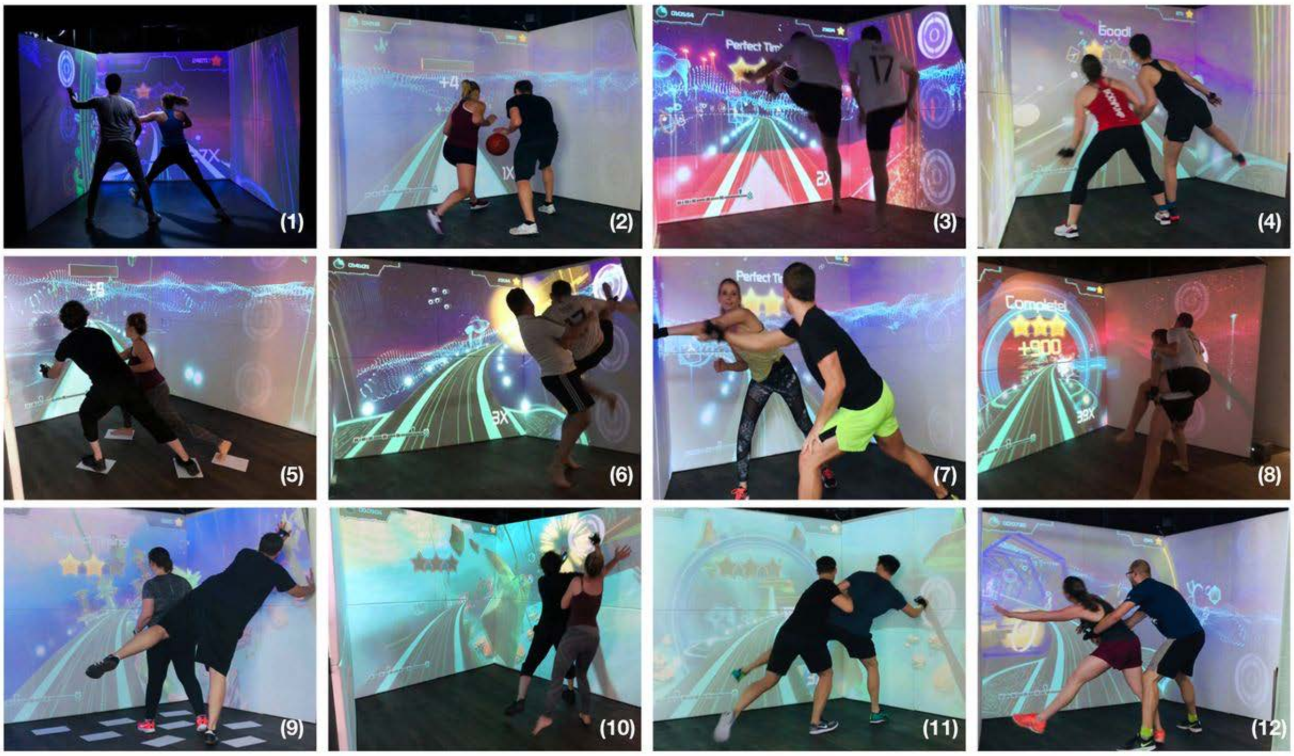

Figure 9: Participants performing different cooperative (1–9) and competitive (10–12) multiplayer versions of the ExerCube.

The tested variations supported a rich training and social experience. The majority of participants preferred collaborative modes of play because this encouraged communication and social interaction. The competitive mode was preferred by the minority. If preferred, pairs liked how it was more unstructured and chaotic (but also more risky from the physical perspective). Players further highlighted the experimental qualities of play (e.g. kicking walls, sliding in paper, using props, wearing controllers on different body parts etc.). Physical contact in cooperative variations and especially holding hands was well liked out of all attachment forms (most useful to "anticipate the other's movements", great feeling of "acting in unison/being united/being even closer/social connectedness"). Physical contact in competitive variations (e.g., hindering the other's movements by physically holding back, occupying more space, etc.) was perceived differently ("awkwardness/too intimate/too close") but became better over time because playing a game and became "a natural thing to do". Face-to-face formations encouraged players to trust and depend on one another and revealed interesting social verbal and non-verbal communication. Social dynamics such as team-leader dynamics, support, and assumptions of the other's fitness were reported. During harder exercises, the team aspects were experienced as particularly important. Fairness and the need for balanced skill levels were often mentioned regarding competitive gameplay.
Regarding perceived exertion, participants found the competitive (due to the drive to win), cooperative (carrying around, increased game speed), and cooperative/competitive (extra exercises) most physically demanding. They further made distinctions between cognitive, physical and social challenges (more verbal coordination when passing negotiating game space or changing behavior).
Among other things, the majority referred to collaborative variations with physical contact as best balanced in fun and exertion.

The potential of the research through design (RtD) method was demonstrated to bring out some interesting design directions that need further explorations to derive a more generalizable RtD-model for socially immersive fitness games. Based on the exploratory findings, the ExerCube multiplayer scenario was further developed. The contributions presented in Manuscript V could inspire others designing in this domain, and support the development of a rich design space for co-located exergames.

Manuscript VI: "HIIT" the ExerCube: Comparing the Effectiveness Of Functional High-Intensity Interval Training in Conventional vs. Exergame-Based Training

After the ExerCube was further developed on all design levels based on the findings from the previous study presented in Manuscript IV, Manuscript VI presents a rounding-off work, with a primary focus on the ExerCube's objectively measured and subjectively experienced effectiveness and a secondary focus on the subjectively experienced attractiveness.
At the time of the study presented in Manuscript VI, first investigations that focused on elaborating the usability and effects of exergame-based high-intensity interval training (HIIT) were published (e.g., Barathi et al, 2019; Farrow et al, 2019; Keesing et al., 2019). However, the promising combination of HIIT with functional training provided by an adaptive, user-centered designed exergame has not yet been investigated nor compared to the conventional counterpart practiced in the fitness market.

The work presented in Manuscript VI explores this research gap, with the goal of better understanding the design requirements of holistic HIIT and its potential in attractive and effective exergames. Therefore, the work provides both design and research contributions: first, a functional HIIT (fHIIT) protocol with physiological and cognitive measures for the ExerCube system to create a HIIT-level functional exergame, as well as a comparable conventional fHIIT protocol, were designed.

To compare the subjective and objective training intensity induced by a single ExerCube session and a single conventional fHIIT session (best practice in the fitness market) with young healthy adults (Figure 10), a within-subjects study was conducted. Furthermore, participants' subjective experience including motivation, flow experience, and enjoyment during both types of training was assessed via questionnaires.

Figure 10: Participants performing a conventional functional high-intensity interval training with a personal trainer (1. and 3. picture from left) and with the ExerCube (2. and 4. picture from left).

It was shown that the ExerCube is a feasible tool for inducing fHIIT-level training intensity. While physical exertion was slightly lower than in the conventional fHIIT condition, the ExerCube condition's average HR reached the fHIIT threshold, but yielded significantly better results for flow, enjoyment, and motivation. It also triggered higher cognitive load, i.e., it achieved dual-domain training.

Even though it was only a single-session comparative study, the work presented in Manuscript VI provides a comparison with high external validity and applicability within the industry. The results thus contribute empirical evidence that an exergame can be used to induce fHIIT-level intensity in addition to positive effects on motivation. Based on the results, it was discussed how effective and motivating exergames should be designed to implement fHIIT and inform future explorations of their effects in terms of associated health benefits and long-term motivation. Among other things, the findings shed light on the promising approach of exergames as dual-domain training, which should be further explored in future R&D work.

References

Adam, C., & Senner, V. (2016). Which motives are predictors for long-term use of exergames?. *Procedia engineering*, *147*, 806-811.

Adams, E. (2014). *Fundamentals of game design*. Pearson Education.

Altimira, D., Mueller, F., Clarke, J., Lee, G., Billinghurst, M., & Bartneck, C. (2016). Digitally Augmenting Sports: An Opportunity for Exploring and Understanding Novel Balancing Techniques. In Proceedings of the CHI Conference on Human Factors in Computing Systems (CHI '16), 1681-1691.

Ballesteros, S., Voelcker-Rehage, C., & Bherer, L. (2018). Cognitive and brain plasticity induced by physical exercise, cognitive training, video games, and combined interventions. *Frontiers in human neuroscience*, *12*, 169.

Barathi, S.C., Finnegan, D.J., Farrow, M., Whaley, A., Heath, P., Buckley, J., Dowrick, P.W., Wuensche, B.C., Bilzon, J.L., O'Neill, E., & Lutteroth, C. (2018). Interactive feedforward for improving performance and maintaining intrinsic motivation in VR exergaming. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems,* 1-14.

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

Benzing, V., Heinks, T., Eggenberger, N., & Schmidt, M. (2016). Acute cognitively engaging exergame-based physical activity enhances executive functions in adolescents. *PloS one*, *11*(12).

Best, J.R. (2015). Exergaming in youth: effects on physical and cognitive health. Z. Psychol. 221, 72–78.

Biddiss, E., & Irwin, J. (2010). Active video games to promote physical activity in children and youth: a systematic review. *Archives of pediatrics & adolescent medicine*, *164*(7), 664-672.

Brown, E., & Cairns, P. (2004, April). A grounded investigation of game immersion. In *CHI'04 extended abstracts on Human factors in computing systems*. 1297-1300.

Buckley, S., Knapp, K., Lackie, A., Lewry, C., Horvey, K., Benko, C., Trinh, J., & Butcher, S. (2015). Multimodal high-intensity interval training increases muscle function and metabolic performance in females. *Applied Physiology, Nutrition, and Metabolism*, *40*(11), 1157-1162.

Byrne, A.M., & Kim, M. (2019). The Exergame as a Tool for Mental Health Treatment. *Journal of Creativity in Mental Health*, *14*(4), 465-477.

Egger, F., Benzing, V., Conzelmann, A., & Schmidt, M. (2019). Boost your brain, while having a break! The effects of long-term cognitively engaging physical activity breaks on children's executive functions and academic achievement. *PloS one*, *14*(3).

Ermi, L., & Mäyrä, F. (2005). Fundamental components of the gameplay experience: Analysing immersion. *Worlds in play: International perspectives on digital games research*, *37*(2), 37-53.

Farrow, M., Lutteroth, C., Rouse, P.C., & Bilzon, J.L. (2019). Virtual-reality exergaming improves performance during high-intensity interval training. *European journal of sport science*, *19*(6), 719-727.

Garber, C.E., Blissmer, B., Deschenes, M.R., Franklin, B.A., Lamonte, M.J., Lee, I.M., Nieman, D.C., & Swain, D.P. (2011). American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Medicine and science in sports and exercise*, *43*(7), 1334-1359.

Gerling, K.M., Miller, M., Mandryk, R.L., Birk, M.V., & Smeddinck, J.D. (2014). Effects of balancing for physical abilities on player performance, experience and self-esteem in exergames. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* 2201-2210.

Gough, C. (2019). Number of active video gamers worldwide from 2014 to 2021. Available at: https://www.statista.com/statistics/748044/number-video-gamers-world/, assessed June 6th, 2020.

Gough, C. (2019). Distribution of video gamers worldwide in 2017, by age group and gender. Available at: https://www.statista.com/statistics/722259/world-gamers-by-age-and-gender/, assessed June 6th, 2020.

Hardy, S., Dutz, T., Wiemeyer, J., Göbel, S. and Steinmetz, R. (2015). Framework for personalized and adaptive game-based training programs in health sport. Multimedia Tools and Applications 74, 5289-5311.

Hoffmann, K., Hardy, S., Wiemeyer, J., & Göbel, S. (2015). Personalized Adaptive Control of Training Load in Cardio-Exergames—A Feasibility Study. *Games for health journal*, *4*(6), 470-479.

Höök, K., Jonsson, M.P. Ståhl, A. Mercurio, J. (2016). Somaesthetic Appreciation Design. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16), 3131-3142.

Joronen, K., Aikasalo, A., & Suvitie, A. (2017). Nonphysical effects of exergames on child and adolescent well-being: a comprehensive systematic review. *Scandinavian journal of caring sciences*, *31*(3), 449-461.

Kajastila, R., & Hämäläinen, P. (2014). Augmented climbing: interacting with projected graphics on a climbing wall. In *CHI'14 Extended Abstracts on Human Factors in Computing Systems,* 1279-1284.

Kappen, D. L., Mirza-Babaei, P., & Nacke, L. E. (2019). Older adults' physical activity and exergames: a systematic review. *International Journal of Human–Computer Interaction*, *35*(2), 140-167.

Kari, T. (2017). Promoting physical activity and fitness with exergames: Updated systematic review of systematic reviews. In *Transforming gaming and computer simulation technologies across industries,* IGI Global, 225-245.

Keesing, A., Ooi, M., Wu, O., Ye, X., Shaw, L., & Wünsche, B. C. (2019). Hiit with hits: Using music and gameplay to induce hiit in exergames. In *Proceedings of the Australasian Computer Science Week Multiconference,* 1-10.

Ketcheson, M., Ye, Z., & Graham, T. N. (2015). Designing for exertion: how heart-rate power-ups increase physical activity in exergames. In *Proceedings of the 2015 Annual Symposium on Computer-Human Interaction in Play,* 79-89.

Kim, S. Y. S., Prestopnik, N., & Biocca, F. A. (2014). Body in the interactive game: How interface embodiment affects physical activity and health behavior change. *Computers in Human Behavior*, *36*, 376-384.

Kliszczewicz, B., McKenzie, M., & Nickerson, B. (2019). Physiological adaptation following four-weeks of high-intensity functional training. *Vojnosanitetski pregled*, *76*(3), 272-277.

Lee, S., Kim, W., Park, T., & Peng, W. (2017). The psychological effects of playing exergames: A systematic review. *Cyberpsychology, Behavior, and Social Networking*, *20*(9), 513-532.

Li, J., Theng, Y. L., & Foo, S. (2016). Effect of exergames on depression: a systematic review and meta-analysis. *Cyberpsychology, Behavior, and Social Networking*, *19*(1), 34-42.

Loke, L., Larssen, A. T., Robertson, T., & Edwards, J. (2007). Understanding movement for interaction design: frameworks and approaches. *Personal and Ubiquitous Computing*, *11*(8), 691-701.

Lu, A.S., Kharrazi, H., Gharghabi, F., & Thompson, D. (2013). A systematic review of health videogames on childhood obesity prevention and intervention. *GAMES FOR HEALTH: Research, Development, and Clinical Applications*, *2*(3), 131-141.

Lyons, E.J. (2015). Cultivating engagement and enjoyment in exergames using feedback, challenge, and rewards. *Games for health journal*, *4*(1), 12-18.

MacRea, A., & Robertson, J. (2013). Understanding exergame users' physical activity, motivation and behavior over time. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* 1251-1260.

Márquez Segura, E., Waern, A., Moen, J., & Johansson, C. (2013). The design space of body games: technological, physical, and social design. In *Proceedings of the SIGCHI conference on Human Factors in computing systems,* 3365-3374.

Marshall, J., & Linehan, C. (2020). Are Exer-Games Exercise? A Scoping Review of the Short Term Effects of Exertion Games. *IEEE Transactions on Games*.

Martin, A.L. & Wiemeyer, J. (2012a). Technology-mediated experience of space while playing digital sports games. International Journal of Computer Science in Sport, 11 (Special Edition 1: Serious Games - Theory, Technology & Practice), pp. 135-146.

Martin, A.L. & Wiemeyer, J. (2012b). The Impact of Different Gaming Interfaces on Spatial Experience and Spatial Presence - A Pilot Study. In St. Göbel, J. Wiemeyer, B. Urban und Müller W. (Eds.). E-Learning and Games in Training, Education, Health and Sports. Springer Lecture Notes in Computer Science, GameDays 2012, pp. 177-182.

Martin, A.L., Götz, U., & Bauer, R. (2014). Development of task-specific RehabGame settings for robot-assisted pediatrie movement therapies. In *2014 IEEE Games Media Entertainment,* IEEE, 1-4.

Martin, A.L., and Kluckner, V.J. (2014). Player-centred Design Model for psychophysiological adaptive Exergame Fitness Training for Children. In Proceedings of the Games for Health Europe Conference 2014 (GFH Europe '14), 105-109.

Martin-Niedecken, A.L., & Götz, U. (2017). Go with the dual flow: Evaluating the psychophysiological adaptive fitness game environment “Plunder Planet”. In *Joint International Conference on serious games,* Springer, Cham, 32-43.

Martin-Niedecken, A.L. (2017). Exploring Spatial Experiences of Children and Young Adolescents While Playing the Dual Flow-Based Fitness Game “Plunder Planet”. In Proceedings of the International Conference on Computer-Human Interaction Research and Application (CHIRA '17), 218-229.

Martin-Niedecken, A.L., & Mekler, E.D. (2018). The ExerCube: Participatory Design of an Immersive Fitness Game Environment. In *Joint International Conference on Serious Games,* Springer, Cham, 263-275.

Martin-Niedecken, A.L., Rogers, K., Turmo Vidal, L., Mekler, E.D., & Márquez Segura, E. (2019). ExerCube vs. Personal Trainer: Evaluating a Holistic, Immersive, and Adaptive Fitness Game Setup. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems,* 1-15.

McRae, G., Payne, A., Zelt, J. G., Scribbans, T. D., Jung, M. E., Little, J. P., & Gurd, B. J. (2012). Extremely low volume, whole-body aerobic–resistance training improves aerobic fitness and muscular endurance in females. *Applied Physiology, Nutrition, and Metabolism*, *37*(6), 1124-1131.

Menz, V., Marterer, N., Amin, S. B., Faulhaber, M., Hansen, A. B., & Lawley, J. S. (2019). Functional Vs. Running Low-Volume High-Intensity Interval Training: Effects on VO2max and Muscular Endurance. *Journal of sports science & medicine*, *18*(3), 497.

Mueller, F., & Isbister, K. (2014). Movement-based game guidelines. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* 2191-2200.

Mueller, F., Khot, R. A., Gerling, K., & Mandryk, R. (2016). Exertion games. Found. Trends Hum. Comput. Interact. 10, 1–86.

Mueller, F.F., Gibbs, M.R., Vetere, F., & Edge, D. (2017). Designing for bodily interplay in social exertion games. *ACM Transactions on Computer-Human Interaction (TOCHI)*, *24*(3), 1-41.

Mueller, F., Vetere, F., Gibbs, M., Edge, D., Agamanolis, St., Sheridan, J., & Heer, J.(2012). Balancing exertion experiences. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12), 1853-1862.

Mura, G., Carta, M.G., Sancassiani, F., Machado, S., & Prosperini, L. (2018). Active exergames to improve cognitive functioning in neurological disabilities: a systematic review and meta-analysis.

Oh, Y., & Yang, S. (2010). Defining exergames & exergaming. *Proceedings of Meaningful Play*, 1-17.

Pasch, M., Bianchi-Berthouze, N., van Dijk, B., & Nijholt, A. (2009). Movement-based sports video games: Investigating motivation and gaming experience. *Entertainment Computing, 1*(2), 49-61.

Pinto, A. J., Dunstan, D. W., Owen, N., Bonfá, E., & Gualano, B. (2020). Combating physical inactivity during the COVID-19 pandemic. *Nature Reviews Rheumatology*, 1-2.

Regal, G., Sellitsch, D., Kriglstein, S., Kollienz, S., & Tscheligi, M. (2020). Be Active! Participatory Design of Accessible Movement-Based Games. In *Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction*, 179-192.

Schättin, A., Arner, R., Gennaro, F., & de Bruin, E.D. (2016). Adaptations of prefrontal brain activity, executive functions, and gait in healthy elderly following exergame and balance training: a randomized-controlled study. *Frontiers in aging neuroscience*, *8*, 278.

Scheid, C. (2013). Eine Erkundung zur Methodologie sozialwissenschaftlicher Analysen von gezeichneten und gemalten Bildern anhand der Analyse zweier Kinderzeichnungen. In *Forum Qualitative Sozialforschung/Forum: Qualitative Social Research,* 14(1).

Sinclair, J., Hingston, P., & Masek, M. (2007). Considerations for the design of exergames. In *Proceedings of the 5th international conference on Computer graphics and interactive techniques in Australia and Southeast Asia,* 289-295.

Sinclair, J., Hingston, P., & Masek, M. (2009). Exergame development using the dual flow model. In *Proceedings of the Sixth Australasian Conference on Interactive Entertainment,* 1-7.

Sinclair, J., Hingston, P., Masek, M., & Nosaka, K. (2010, December). Testing an exergame for effectiveness and attractiveness. In *2010 2nd International IEEE Consumer Electronics Society's Games Innovations Conference.* 1-8.

Skalski, P., Tamborini, R., Shelton, A., Buncher, M., & Lindmark, P. (2011). Mapping the road to fun: Natural video game controllers, presence, and game enjoyment. *New Media & Society*, *13*(2), 224-242.

Stach, T., Graham, T.C., Yim, J., & Rhodes, R.E. (2009). Heart rate control of exercise video games. In *Proceedings of Graphics interface 2009*. Canadian Information Processing Society, 125-132.

Stach, T., & Graham, T.N. (2011). Exploring haptic feedback in exergames. In *IFIP conference on human-computer interaction*. Springer, Berlin, Heidelberg, 18-35.

Staiano, A. E., & Calvert, S. L. (2011). Exergames for physical education courses: Physical, social, and cognitive benefits. *Child development perspectives*, *5*(2), 93-98.

Stojan, R., & Voelcker-Rehage, C. (2019). A systematic review on the cognitive benefits and neurophysiological correlates of exergaming in healthy older adults. *Journal of clinical medicine*, *8*(5), 734.

Sween, J., Wallington, S.F., Sheppard, V., Taylor, T., Llanos, A. A., & Adams-Campbell, L. L. (2014). The role of exergaming in improving physical activity: a review. *Journal of Physical Activity and Health*, *11*(4), 864-870.

Tondello, G.F., Mora, A., Marczewski, A., & Nacke, L.E. (2019). Empirical validation of the gamification user types hexad scale in English and Spanish. *International Journal of Human-Computer Studies*, *127*, 95-111.

Totilo, S. (2019). Nintendo's new exercise adventure game is ingenious, even if it makes me look ridiculous. Available at: https://kotaku.com/nintendo-s-new-exercise-adventuregame-is-ingenious-ev-1839133470, assessed June 6th, 2020.

Trost, S.G., Owen, N., Bauman, A.E., Sallis, J.F., & Brown, W. (2002). Correlates of adults' participation in physical activity: review and update. *Medicine & science in sports & exercise*, *34*(12), 1996-2001.

Trost S.G., Blair S.N., & Khan K.M. (2014). Physical inactivity remains the greatest public health problem of the 21st century: evidence, improved methods and solutions using the "7 investments that work" as a framework. *British Journal of Sports Medicine*, 48, 169-170.

Valenzuela, T., Okubo, Y., Woodbury, A., Lord, S.R., & Delbaere, K. (2018). Adherence to technology-based exercise programs in older adults: a systematic review. *Journal of Geriatric Physical Therapy*, *41*(1), 49-61.

Vara, M.D., Baños, R.M., Rasal, P., Rodríguez, A., Rey, B., Wrzesien, M., & Alcañiz, M. (2016). A game for emotional regulation in adolescents: The (body) interface device matters. *Computers in Human Behavior*, *57*, 267-273.

Weeks, J.R. (2020). Population: An introduction to concepts and issues. Cengage Learning.

Weibel, D., & Wissmath, B. (2011). Immersion in computer games: The role of spatial presence and flow. *International Journal of Computer Games Technology*, *2011*.

World Health Organization (2020). WHO guidelines on physical activity and sedentary behaviour: at a glance.

Xiong, S., Zhang, P., & Gao, Z. (2019). Effects of Exergaming on Preschoolers' Executive Functions and Perceived Competence: A Pilot Randomized Trial. *Journal of clinical medicine*, *8*(4), 469.

3 Manuscript I: Design and Evaluation of a Dynamically Adaptive Fitness Game Environment for Children and Young Adolescents

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Author Contributions:
Anna Lisa Martin-Niedecken is the initiator of the presented work and the main author of the paper. She was responsible for the conception, design and conduction of the study, the co-development of the exergame, the analysis and interpretation of the data and writing of the manuscript. Ulrich Götz critically reviewed the manuscript and assisted for the revision of the paper.

3.1 Abstract

Traditional gym and fitness exercise regimens are currently being enhanced with innovative technology and interactive gamification systems. Exergame gyms offer body-centered games, which are controlled by relating the level of the user's physical activity to interactive coordinative and cognitive game demands. This approach can further be enhanced by implementing dynamically adaptive game balancing mechanisms, and specifically designed full-body motion controllers, to yield an optimal play/training session. Building on results of interdisciplinary game research, we designed and evaluated a dynamically-adaptive fitness game environment for children and young adolescents. This setting increases the motivating effects of fitness training, and can be used in addition, or as alternative to standard fitness programs.

3.2 Introduction

Contemporary gym exercising and fitness training regimens are characterized by being expanded by interactive technology, such as smartphone training Apps[1] or Virtual Reality (VR) cubes[2], and particularly, by gamification systems[3]. New gym setups offer a wide range of so-called exergame (exertion/exercise + gaming) fitness training options[4,5]. Data from motion controllers is used to control coordinative and cognitive in-game actions of body-centered games, converting the user's physical activity into game input data.

Commercial exergames for home use show substantial differences to gym fitness training exergames, in relation to their setups and input devices. Commercial exergames are controlled by input devices, as for example the Nintendo Wii® Balance Board or the Sony Move® motion controller, connecting to such home entertainment systems as Xbox®, PlayStation® or Wii® console. Exergame fitness training controllers, however, demand the types of physical activity related to motor skills. While commercial exergames simplify movement patterns and demand less physical strain, gym-fitness training exergames demand physical exertion of the user.

This approach can be further enhanced: if exergame training and gameplay matches the user's momentary physical and emotional state, s/he is able to enter the so-called "Dual Flow" (Sinclair et al., 2017). Dual flow can be described as a condition of optimal training and well-being, in which a player/user is neither physiologically overstrained nor under-challenged (effectiveness), and feels well balanced between psychological stress and boredom (attractiveness). Dual flow can, for example, be obtained by the implementation of "dynamic game balancing" (DGB) (e.g., Mueller et al., 2012; Altimira et al., 2016) and, according to Hardy et al. (2014), increases the player's/user's motivation. The "Game Flow Model" (Sweetser & Wyeth, 2005) suggests that game flow depends on factors such as concentration, challenge, player skills, control, clear goals, feedback, immersion and social interaction. Game research of isolated game experience factors has shown that gameplay is also affected by simultaneous effects of mutually dependent factors: e.g. the feeling of flow results from the experience of immersion and involvement (Weibel & Wissmath, 2011), which again is related to the feeling of spatial presence (Witmer & Singer, 1998).

Further research focuses on the impacts added by specifically designed input controllers. Skalski et al. (2010) found that the perceived "naturalness" of game controller interactions shapes the sense of spatial presence. Stach and Graham (2011) showed that the type of interface feedback affects the gameplay experience: haptics matching on-screen actions improved immersion and enjoyment. Vara et al. (2016) highlighted that the types of interface devices used for controlling the games, and the involvement of the entire human body into the gameplay are important variables in the emotional experiences of serious

[1] https://www.freeletics.com
[2] http://www.lesmills.com/immersive-fitness/
[3] https://zombiesrungame.com
[4] http://www.motionfitness.com
[5] http://www.pavigym.com

games. Kim et al. (2014) found that an embodied interface makes the exergame experience more realistic and enjoyable.

Therefore, to optimize further developments of exergames for fitness training, their design should offer multisensory experiences and motivating gameplay scenarios. Specific developments need to focus on the design of body-centered game controllers in order to achieve a multimodal effect.

3.3 Designing a Dynamically-Adaptive Exergame Training Setting for Young People

Based on related work, the design of our dynamically adaptive exergame "Plunder Planet" focused on the development of an immersive, motivating dual-flow game scenario, and a full-body motion game controller (FBMC). The development is targeted towards children and young adolescents aged 10-14 years, covering the range from physically active to non-exercising individuals. The game can be used as an alternative or a supplement to traditional fitness training.

3.3.1 Concept Design & Gameplay

First concepts incorporated the prototype game "Flitz!" (Martin & Kluckner, 2014), in which we conducted user surveys to specify the target group's preferences in art style, gaming topic, and in-game actions. Concepts for an adaptive gameplay were iteratively derived from these findings and led to the development of the game, making use of the game engine Unity3D®. "Plunder Planet" was realized in close collaboration with Koboldgames GmbH, which contributed game programming, game visuals, and sound design.

Figure 1: Game Setting: In the sci-fi setting of "Plunder Planet", the player navigates flying pirate ship on the hunt for treasures. Opponents and obstacles have to be tackled on the rushing journey through canyons of a desert planet.

The game (Figure 1) starts with a how-to tutorial for control of the six possible in-game actions, which are triggered by either hitting large buttons positioned in the training area, or interacting with the Kinect® sensor (see section "Controller Setups"). In the game, a flying pirate ship has to be navigated through a desert racecourse filled with obstacles (rocks and fossils), and activated shields defend against strikes of opponents (giant sandworms). On the track, reward items (crystals), each worth 100 points, can be collected and added to a cumulative overall score. Every collision with an obstacle or a sandworm results in the deduction of 50 points from the score.

After a 2.5-minute warm-up/familiarization phase of navigating the ship, the players have to also defend the ship against attacks of the opponents, now using all six in-game actions. If the training is extended to further runs, the game demands all in-game actions from the start. The ship is displayed from an immersive third person perspective. Quick reactions and accurate timing of full-body movements are essential for navigation and shield-activation. Direct sound feedback illustrates collisions with obstacles, collections of crystals, and navigation movements of the ship.

3.3.2 Adaptive Game Mechanics

In the current state of development, three adaptive game mechanics (Figure 2) are implemented and tested, according to the approaches of “Dual Flow” and “Game Flow”. One adaptive variable targets the physiological dimension of the exergame session: A Polar H7 sensor measures the user’s heart rate (HR) during the game, while the Trainer-GUI (see section Trainer-GUI) offers the possibility to gradually adjust the frequency of obstacles in real-time in order to reach a predefined individual training load. Two other variables target the psychological dimension of the game: The in-game performance is assessed by the number of collisions, successfully overcome obstacles and opponents defended. As a result, the track varies between easier or harder layouts (straight and even, or curvy and hilly). Also, overcoming obstacles can become easier or harder (by varying the arrangements of the obstacles). For all variables, the quality of adjustment features three independent levels of difficulty (low, medium and high, and each with three sub-levels: 0.0-0.3; 0.4-0.6; 0.7-1).

Five minutes after the start, and again 2.5 minutes later, the course of the game slows down for 20 seconds, during which the ship is in repair. This short pause offers relief from cognitive tasks; at the same time, the repair requires increased physical user input through upper-body movements.

Figure 2: In-game screenshots of the adaptive gameplay.

Figure 3: “Plunder Planet” full-body motion controller (FBMC) study setup.

Figure 4: “Plunder Planet” Kinect® study-setup.

3.3.3 Controller Setups

Currently, two forms of input devices are used for the physical control of “Plunder Planet”. One, the FBMC, offers haptic feedback, and demands coordinative and spatial orientation skills (Figure 3). The other, a setup with the gesture-based Kinect® sensor allows for a high freedom of movement (Figure 4).

Our review of related work led to the development of a FBMC which consists of six large buttons, positioned around the user’s moving area. The buttons can be adjusted both in height and width, and offer a distinct haptic feedback. To control the in-game actions, users must move/jump to the left or right, and hit four buttons, placed above their heads and at shoulder level. Two additional buttons are placed in front of the player, shortly above floor level. The buttons are connected to the Unity3D® game engine via Phidget Board.

To contrast our controller development, and to validate possible extensions, we also used the Kinect2® sensor as an input device. This implementation varies required navigation skills in comparison to the FBMC by providing a non-haptic, but still body-centered input method. Tracked by an infrared-sensor, the user can move around more freely, even jump and squat. The sensor can be individually calibrated for the user.

3.3.4 Trainer-GUI

In the current state of development, “Plunder Planet’s” game mechanics can be manually adapted to the user’s physical and emotional condition in real-time, via Trainer-GUI on an external computer (Figure 5). With regard to the user’s HR and in-game performance, the trainer can adjust the physiological and psychological levels of difficulty. The Kinect® sensor can also be calibrated via Trainer-GUI. Besides, we implemented explorative adaption modes for further experimental balancing tests, as well as data protocol functions.

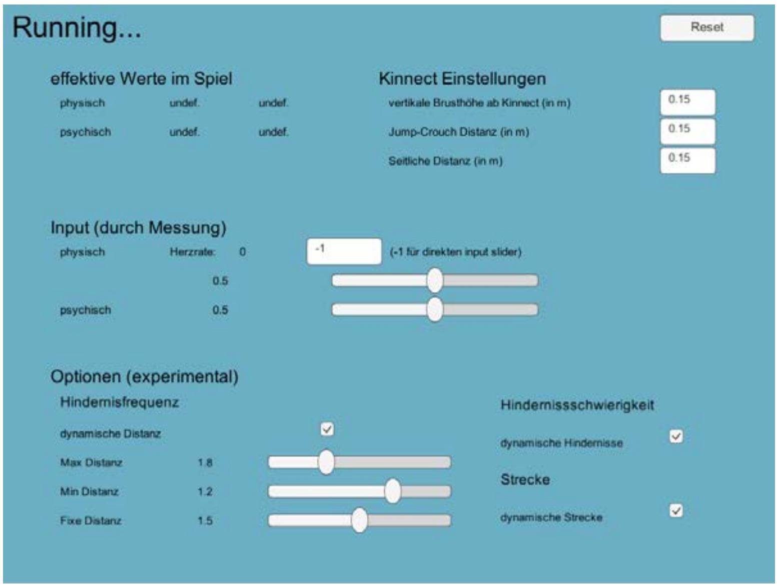

Figure 5: Trainer-GUI: The user wears a Polar® H7 sensor connected to the Trainer-GUI. By calculating the individual maximum HR (HR_{max}=220–age;(Robergs & Landwehr, 2002)) the optimal training level (Gabriel et al., 2014) for each user/sports type can be derived (health zone, fat burning zone, aerobic and anaerobic zone).

3.4 Feasibility Study

In order to validate effectiveness, attractiveness and motivational effects of the adaptive exergame design, a feasibility study was undertaken. We also examined the impact of the two different game controllers on the game and spatial presence experience. We recruited 16 children and young adolescents (13 males and 3 females) with and without experience with playing video games (8 GX and 8 nGX), and who did or did not frequently enjoy athletic activities (8 A and 8 nA). The age of the participants ranged from 10 to 14 years (M=12.1 years; SD=1.29). For the intervention, participants were divided into four equal groups (GX/A; nGX/A; GX/nA; nGX/nA). To balance sequence effects, eight participants started the exergame session with the FBMC, while eight participants started using the Kinect® sensor. Each exergame setup was played twice, every session took 10 minutes. Every 3 seconds psychophysiological data (HR, in-game performance and difficulty level) of all players and play sessions were recorded. Participants were treated in accordance with the Declaration of Helsinki (World Medical Association, 1991).

Before starting the sessions, participants were asked questions about their personal preferences in gaming and sports. After two completed runs with one controller, participants were asked to answer two questionnaires; the “KidsGEQ” (Poels et al., 2008) for their gameplay experiences, applying a 5-point Likert scale (from 0=I do not agree at all to 4=I fully agree) and the “SPES” (Hartmann et al., 2015), applying a 5-point Likert scale concerning their spatial presence experience. Additionally, participants were asked to answer questions about enjoyment and other game flow dimensions, again applying a 5-point Likert scale. Finally, they were asked comparative questions about both controller setups.

3.4.1 Preliminary Results

For statistical analysis SPSS 24 was used. A 4(groups) x 2(devices) x 4(items) ANOVA with repeated measurements on the last factor revealed no significant main effects or interactions of the groups, devices or items for the spatial presence experiences.

GX/A and GX/nA participants ranked all items of self-location (e.g., “I felt like I was actually present in the environment”) much higher than nGX/A and nGX/nA participants (Table 1). Generally, all subjects reported a slightly better feeling of self-location using the Kinect® setup, but only if they belonged to the group with athletic experiences. GX/A and GX/nA participants valued possible actions (e.g., “I felt like I could jump into the action.”) much higher than nGX/A and nGX/nA participants. Again, the Kinect® setup tends to be ranked slightly better by all groups, except for nGX/A participants. This group reported a better feeling of possible actions playing with the FBMC.

Table 1: Means and standard deviation of spatial presence experience by group & device.

Items	GX/A		GX/nA		nGX/A		nGX/nA	
	Kinect	Controller	Kinect	Controller	Kinect	Controller	Kinect	Controller
SPES SL1	3.25 (.50)	3.00 (.82)	2.75 (1.26)	2.75 (1.26)	2.00 (1.16)	1.75 (.50)	1.50 (1.29)	2.50 (1.73)
SPES SL2	3.25 (.50)	3.00 (1.41)	2.75 (1.26)	2.05 (1.29)	1.50 (1.73)	2.25 (.50)	2.25 (.96)	1.50 (1.92)
SPES SL3	3.00 (.00)	2.75 (1.89)	2.00 (1.41)	2.25 (.96)	1.75 (1.50)	1.75 (.50)	1.75 (1.71)	1.00 (1.16)
SPES SL4	2.75 (.50)	3.00 (.00)	3.00 (.82)	2.75 (1.26)	1.75 (1.50)	1.75 (.50)	1.75 (1.71)	2.00 (1.41)
SPES PA1	3.00 (.00)	3.00 (.00)	3.00 (1.41)	3.00 (.82)	2.25 (1.50)	2.50 (.58)	2.50 (1.29)	2.25 (1.26)
SPES PA2	3.25 (.50)	2.75 (1.23)	3.00 (1.41)	2.75 (1.26)	2.00 (1.16)	2.25 (.50)	2.75 (.96)	2.75 (1.50)
SPES PA3	3.50 (.58)	3.50 (.58)	3.25 (.50)	3.00 (.82)	2.00 (1.16)	2.75 (.50)	2.50 (1.29)	1.25 (.50)
SPES PA4	3.25 (.96)	3.00 (.82)	2.00 (1.83)	2.25 (.96)	2.25 (2.06)	1.75 (.96)	1.75 (1.71)	1.00 (.82)

With regard to the game experience dimension “positive affect” (example item: “I felt good while playing”) a 4(groups) x 2(devices) x 3(items) ANOVA with repeated measurements on the last factor revealed a significant effect of groups ($F_{3, 12}$=3.56, p=.05, partial η^2=.47). For “immersion” (example item: “The game was beautiful”) a significant main effect of groups ($F_{3, 12}$=4.18, p=.03, partial η^2=.51) was found. For the feeling of “flow” (example item: “I felt like I was inside the game”) a marginally significant interaction of groups and items ($F_{6, 24}$=2.04, p=.10, partial η^2=.34) could be demonstrated. The feeling of “competence” (example item: “I was good at it”) showed a marginally significant main effect of device ($F_{1, 12}$=4.48, p=.05, partial η^2=.28) and a marginally significant interaction of groups and items ($F_{6, 24}$=2.55, p=.06, partial η^2=.39). For “negative affects” (example item: “I felt bored”) ANOVA revealed a marginally significant interaction of groups and items ($F_{6, 24}$=2.1, p=.09, partial η^2=.34). For “tension” (example item: “The game made me nervous”) and “challenge” (example item: “I felt challenged by the game”) no significant main effects or interactions were found.

Most items of game experience were ranked better by GX/A and GX/nA participants than by nGX/A and nGX/nA participants (Table 2). Comparing the ratings for playing with two different devices, for the immersion-item “I could use my fantasy in the game”, and for all items of “competence”, subjects of all groups gave better values for the FBMC. For most flow items, all groups voted slightly better for the Kinect®. All groups which experienced higher flow and immersion also had a greater feeling of spatial presence. Generally, GX/A participants tended to prefer Kinect® while non-athletic participants (GX/nA and nGX/nA) tended to prefer FBMC for all KidsGEQ-dimensions.

Table 2: Means and standard deviation of game experience by group & device.

Items	GX/A		GX/nA		nGX/A		nGX/nA	
	Kinect	Controller	Kinect	Controller	Kinect	Controller	Kinect	Controller
GEQ_PosA1	2.50 (.58)	2.50 (1.00)	2.00 (.82)	1.50 (.56)	1.50 (1.26)	2.00 (1.83)	1.75 (1.23)	1.25 (1.26)
GEQ_PosA2	3.75 (.50)	3.75 (.50)	3.25 (.96)	2.75 (.50)	2.75 (1.26)	3.00 (.00)	2.75 (.96)	3.25 (.96)
GEQ_PosA3	3.25 (.96)	3.75 (.50)	3.00 (.82)	3.00 (.82)	2.00 (1.41)	2.25 (.50)	1.50 (.1.00)	2.25 (1.41)
GEQ_NegA1	.00 (.00)	.00 (.00)	.00 (.00)	.00 (.00)	1.00 (.96)	.00 (.00)	1.00 (.50)	.75 (.50)
GEQ_NegA2	1.25 (1.00)	.25 (.50)	.00 (.00)	.25 (.50)	1.00 (.96)	.00 (.00)	1.00 (.50)	.25 (.50)
GEQ_NegA3	.00 (.00)	.00 (.00)	.00 (.00)	.00 (.00)	.25 (.50)	.00 (.00)	.25 (.50)	.25 (.50)
GEQ_Im1	2.75 (.50)	2.75 (1.29)	1.50 (.58)	2.25 (.96)	1.50 (1.00)	2.00 (.82)	1.00 (1.41)	1.25 (.50)
GEQ_Im2	3.50 (.58)	3.25 (.50)	3.00 (.82)	3.25 (.96)	2.25 (.96)	2.50 (.58)	2.25 (.50)	2.25 (.50)
GEQ_Im3	3.50 (.58)	3.75 (.50)	3.00 (.82)	3.25 (.50)	2.25 (1.00)	3.00 (.00)	2.25 (.96)	2.50 (.50)
GEQ_Flow1	4.00 (.00)	3.50 (1.00)	3.25 (.96)	3.25 (.50)	3.25 (.96)	2.75 (.50)	2.50 (1.73)	3.25 (.96)
GEQ_Flow2	3.25 (.96)	2.50 (1.73)	3.25 (.96)	2.75 (.96)	2.25 (1.26)	2.25 (.50)	3.50 (1.00)	2.00 (.82)
GEQ_Flow3	3.75 (.50)	3.00 (1.00)	3.00 (.82)	2.75 (.96)	2.25 (1.50)	1.75 (.50)	3.25 (.96)	1.75 (1.00)
GEQ_Comp1	2.75 (.50)	3.25 (.50)	3.00 (.82)	3.25 (.50)	1.75 (1.50)	2.00 (.82)	1.00 (.82)	2.50 (1.29)
GEQ_Comp2	2.50 (.58)	3.50 (.58)	3.00 (1.41)	3.00 (.82)	2.25 (1.50)	2.75 (.96)	1.50 (1.29)	2.25 (.96)
GEQ_Comp3	1.75 (1.26)	2.75 (.96)	2.25 (1.50)	2.25 (.96)	2.25 (1.71)	2.50 (.58)	1.50 (1.29)	1.75 (1.26)
GEQ_Chall1	3.35 (.50)	3.50 (.58)	3.00 (.82)	3.00 (.00)	2.75 (1.26)	2.75 (.50)	2.75 (.96)	2.75 (.96)
GEQ_Chall2	4.00 (.00)	3.75 (.50)	3.75 (.50)	3.50 (.58)	2.75 (1.50)	3.50 (.58)	3.00 (.82)	3.25 (.96)
GEQ_Chall3	3.00 (1.41)	2.25 (1.71)	3.25 (.96)	2.50 (.58)	3.00 (1.41)	1.00 (.82)	2.74 (1.26)	3.50 (.58)
GEQ_Ten1	1.25 (1.50)	.50 (1.71)	.75 (1.50)	.50 (1.00)	.75 (1.50)	.75 (.50)	2.00 (1.41)	1.00 (1.41)
GEQ_Ten2	.75 (.96)	.75 (.96)	2.00(1.23)	1.50 (1.29)	.75 (1.50)	.25 (.50)	1.25 (1.19)	1.00 (.82)
GEQ_Ten3	.00 (.00)	.75 (.50)	.75 (.50)	.50 (.50)	.75 (.96)	.25 (.50)	1.75 (1.71)	1.00 (.82)

Concerning the additional questions on “enjoyment”, “dual flow” and “motivation”, subjects rated the question “Did you enjoy the game?” with a 3.44 (SD=.63) for the Kinect® setup and a 3.63 (SD=.50) for the FBMC. For the question “Have you been optimally challenged?” participants rated the Kinect® setup with a 3.25 (SD=.68) and FBMC with a 3.63 (SD=.50). For “Did the game motivate you to move?” subjects rated Kinect® with a 3.44 (SD=.63) and FBMC with a 3.31 (SD=.79).

Participants’ overall ranking revealed that N=6 of 16 subjects voted for the Kinect® setup and N=6 for the FBMC for a better feeling during play, while N=4 participants liked the feeling of both devices. Regarding a more natural feeling, N=8 participants reported a higher “naturalness” of the Kinect® setup, while N=6 preferred the FBMC, and N=2 liked both conditions. There is a higher tendency to get immersed with the Kinect® setup, while more fun was reported for the FBMC setup. Most subjects would play with both devices again. Participants with athletic experience mostly preferred playing with the Kinect® setup, which features free movements of the body. Subjects without athletic experience preferred the feeling of cognitive and coordinative challenge in the more restricted environment of the FBMC.

After 4 play sessions (2x Kinect® sensor and 2x FBMC), each participant had been physically active for 40 minutes. The average HR lay between 125-145 beats per minute (bpm) for the FBMC and 130-160 bpm for the Kinect® setup. Thus, participants worked-out within the “fat burning zone” (60-70% of HR_{max}) and the “aerobic zone” (70-80% of HR_{max}). Playing with the Kinect® setup, the athletic participants’ average levels of DGB mechanisms were around 0.7 for the psychological and 0.8 for the physiological sub-level; playing with the FBMC the levels reached between 0.8 and 0.9.

3.5 Discussion, Outlook & Acknowledgement

In conclusion, “Plunder Planet” and its DGB mechanics work both with the controller setups of Kinect® and FBMC. The exergame provides fitness training within a motivating and challenging setting for children and young adolescents of different abilities.

Based on the results of the feasibility study, we would like to further develop “Plunder Planet” and the FBMC setup for fitness training applications. The Trainer-GUI will be implemented as portable tablet-device, and the DGB mechanisms will be automated. A planning and evaluation program shall be integrated into the GUI. We would like to conduct further investigations and compare the effects on fitness and motivation of a dynamically balanced fitness game setting versus a traditional workout setting in the context of a 12-week intervention.

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3.7 References

Altimira, D., Mueller, F., Clarke, J., Lee, G., Billinghurst, M. and Bartneck, C. (2016). Digitally Augmenting Sports: An Opportunity for Exploring and Understanding Novel Balancing Techniques. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16), 1681-1691.

Gabriel, H., Wick, C. Puta, C. (2007). Components of preventive health training - endurance, strength, flexibility and coordination (in German). In Sports in Prevention: Manual for trainers, sports teachers and physiotherapists (in German) (2nd ed.), L. Vogt & A. Neumann (Eds.), 33-65.

Hardy, S., Kern, A., Dutz, T., Weber, C. Göbel, S. and Steinmetz, R. (2014). What makes games challenging? Considerations on how to determine the challenge posed by an exergame for balance training. In Proceedings of the 2014 ACM International Workshop on Serious Games (Serious Games '14), 57-62.

Hartmann, T., Wirth, W., Schramm, H., Klimmt, C., Vorderer, P., Gysbers, A., Böcking, S., Ravaja, N., Laarni, J., Saari, T., Gouveia, F. and Sacau, A. (2015). The Spatial Presence Experience Scale (SPES): A Short Self-Report Measure for Diverse Media Settings. Journal of Media Psychology 1(1), 1-15.

Kim, S.Y.S., Prestopnik, N. and Biocca, F.A. (2014). Body in the interactive game: How interface embodiment affects physical activity and health behavior change. Computers in Human Behavior 36: 376-384.

Martin, A.L., and Kluckner, V.J. (2014). Player-centred Design Model for psychophysiological adaptive Exergame Fitness Training for Children. In Proceedings of the Games for Health Europe Conference 2014 (GFH Europe '14), 105-109.

Mueller, F., Vetere, F., Gibbs, M., Edge, D., Agamanolis, S., Sheridan, J. and Heer, J. (2012). Balancing exertion experiences. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12), 1853-1862.

Poels, K., Ijsselsteijn, W. and de Kort, Y. (2008). Development of the kids game experience questionnaire. In Proceedings of the Meaningful Play Conference (Meaningful Play '08).

Robergs, R. A. & Landwehr, R. (2002). The surprising history of the „HR_{max}=220-age“ equation. Journal of Exercise Physiology online, 5(2), 1-10.

Sinclair, J., Hingston, P. and Masek, M. (2007). Considerations for the design of exergames. In Proceedings of the 5th international conference on Computer graphics and interactive techniques in Australia and Southeast Asia (GRAPHITE '07), 289- 295.

Skalski, P., Tamborini, R., Shelton, A., Buncher, M. and Lindmark, P. (2010). Mapping the road to fun: Natural video game controllers, presence, and game enjoyment. New Media & Society 13, 2: 1-19.

Stach, T. & Graham, N.T.C. (2011). Exploring haptic feedback in exergames. In Proceedings of the Conference on Human- Computer Interaction (INTERACT '11), 18-35.

Sweetser, P. & Wyeth, P. (2005). GameFlow: a model for evaluating player enjoyment in games. Computers in Entertainment 3(3), 3-3.

Vara, M.D., Baños, R.M., Rasal, P., Rodríguez, A., Rey, B., Wrzesien, B.M. and Alcañiz, M. (2016). A game for emotional regulation in adolescents: The (body) interface device matters. Computers in Human Behavior 57, 267-273.

Weibel, D. & Wissmath, B. (2011). Immersion in computer games: The role of spatial presence and flow. International Journal of Computer Games Technology 2011, Article No. 6: 1-14.

Witmer & Singer, M.J. (1998). Measuring presence in virtual environments: A pressence questionnaire. Presence: Teleoperators and virtual environments 7(3). 225-240.

World Medical Association (1991). Declaration of Helsinki. Law, Medicine & Health Care, 19, 264–265.

4 Manuscript II: Go with the Dual Flow: Evaluating the Psychophysiological Adaptive Fitness Game Environment "Plunder Planet"

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Anna Lisa Martin-Niedecken is the initiator of the presented work and the main author of the paper. She was responsible for the conception, design and conduction of the study, the co-development of the exergame, the analysis and interpretation of the data and writing of the manuscript. Ulrich Götz critically reviewed the manuscript and assisted for the revision of the paper.

4.1 Abstract

Exergaming is approved by health and sport science for its improvement of physical activity and therefore is an attractive way to counteract childhood obesity. The body-centered game genre provides a motivating, multi-modal and -sensory workout experience for the player. But the attractiveness and effectiveness of exergames can be improved even further. Game research points out the need for adaptive exergame environments, which balance player skills and in-game challenges as well as player fitness and workout intensity. This individually adjusted training positively affects the player's engagement, enjoyment, motivation, and physical performance. Numerous studies delivered further insights into the impact of body movements, motion-based controllers and in-game mechanics on the player's gameplay experience, and made suggestions for specific game balancing mechanisms. However, there is limited knowledge on how to design holistic psychophysiological adaptive exergame environments. We aim to fill this gap with the design of the psychophysiological adaptive fitness game environment "Plunder Planet" for children and young adolescents.

We conducted a study which compares the impact of a non-adaptive and an adaptive version of our exergame on the attractiveness and the effectiveness experienced by the player. We were able to show that the adaptive version holds significant benefits compared to the non-adaptive version. Furthermore, the study compared the player's experiences when playing "Plunder Planet" with two different controller types: our specifically developed full-body motion controller and the commercially available Kinect2®. Results confirm our controller design decisions, including the positive impact of haptic feedback and physical guidance on the player's GameFlow experience and enjoyment.

4.2 Introduction

According to the World Health Organization childhood obesity is one of today's most serious public health challenges, even though overweight and obesity as well as related diseases (e.g. diabetes and cardiovascular diseases) could easily be prevented (World Health Organization, 2016). Childhood obesity can be counteracted by regular exercise routines (Mazzeo et al., 2012), which calls for new incentives to motivate younger generations to be more physically active.

One attractive and effective way to solve this problem is through so-called exergames. Exergames (exertion/exercising + gaming) are body-centered games, which require physical motion in order to play (Oh & Yang, 2010).

4.3 Related Work

4.3.1 Effectiveness

Although exergaming was initially conceived as a form of entertainment, researchers and health professionals are interested in adopting these technologies to support healthcare treatments and to promote physical activity and wellbeing for many reasons (Osorio et al., 2012). Numerous sport-scientific and health related studies on both commercially available exergames and specifically designed exergames confirmed the benefits of the "edutainment technology" trend in sport (Wiemeyer & Temper, 2017). Studies suggest that exergames, by having the potential to increase energy expenditure (Murphy et al., 2009) and improve exercise effectiveness and program compliance (e.g., Harris & Reid, 2005), can be effective in fighting obesity, inactivity, and health problems associated with sedentary lifestyles. Additionally, these studies indicate that children enjoy playing exergames, which increases their motivation to keep playing. Furthermore, there is evidence that exergaming positively affects, among other things, the learning of sensorimotor skills (Fery & Ponserre, 2001), coordinative abilities (Sohnsmeyer, 2011) as well as strength and endurance (Sohnsmeyer et al., 2010).

4.3.2 Attractiveness

Game research from interdisciplinary perspectives provides further insights into the theories behind exergames and the impact of the genre on the player's gameplay experience, body and mind. Csikszentmihalyi's flow theory (1990) can be compared with the feeling of complete and energized focus on a particular activity, combined with a high level of enjoyment and fulfillment. An important precursor to the flow experience is the match between a person's skills and the challenges associated with a task, such as playing a game. Weibel and Wissmath (2011) define flow as a result of immersion or involvement in an activity (e.g. playing a game). Sweetser and Wyeth (2005) present the "GameFlow" model which determines the key elements of player enjoyment. According to their approach, the state of game flow is modeled by a mix of elements:

- Concentration: Games should require concentration, and the player should be able to concentrate on the game.
- Challenge: Games should be sufficiently challenging and match the player's level of skill.
- Player skills: Games must support player skill development and mastery.
- Control: Players should feel a sense of control over their actions in the game.
- Clear goals: Games should provide the player with clear goals at appropriate times.
- Feedback: Players must receive appropriate feedback at appropriate times.
- Immersion: Players should experience deep but effortless involvement in the game.
- Social interaction: Games should create opportunities for social interaction.

4.3.2.1 Body

Apart from the mental and cognitive challenge, an additional physical challenge arises while playing an exergame. The bodily exertion greatly influences the player's game experiences. Bianchi-Berthouze (2013) investigated how body movement can be exploited to modulate the quality of gameplay experience, and they were able to identify five classes of movement: task-control movements, task-facilitating movements, role-related movements, affective expression and expression of social behavior. In general, the inclusion of holistic physical activity into gameplay is found to be a positive predictor for the feeling of immersion and engagement (Pasch et al., 2009).

4.3.2.2 Controller

Additionally, the type of controller has a big influence on the player's game experience. Nijhar et al. (2011) found that players become more immersed if the movement recognition precision increases. Similarly, Skalski et al. (2011) discovered that the perceived "naturalness" of game controller interactions shapes the sense of spatial presence, which is related to the feeling of immersion. Stach and Graham (2011) showed that haptics matching on-screen actions improved immersion and enjoyment. Kim et al. (2014) found that an embodied interface improves energy expenditure, player experience and the intention to repeat this experience inside the exergame.

4.3.2.3 Dual Flow

The attractiveness and effectiveness of an exergame can be improved even more, e.g. by a well-balanced adjustment of the physical and psychological aspects of its design. Sinclair et al. (2007) applied the flow theory to the task of playing a physically and mentally challenging exergame, calling it "dual flow". Accordingly, an optimal exergame training has to balance player skills and in-game challenges as well as player fitness and workout intensity to create a maximum positive player experience. The player is then neither physically overstrained nor under-challenged ("effectiveness"), and feels well-balanced between psychological stress and boredom ("attractiveness"). The player experiences the feeling of "being in the zone".

Based on this theoretical framework, there are various approaches investigating and making suggestions for the implementation of a balanced challenge-skill level and the dual flow concept in exergames. For example, "dynamic game balancing" mechanisms (DGB) or "dynamic difficulty adjustments" (DDA) (Altimira et al., 2016) can be implemented on various levels of an exergame environment (in-game, body- and controller-level).

There are several suggestions on how to balance differently skilled players within a multiplayer exergame to simultaneously provide a fun and flow experience for more and less skilled players while playing together or against each other. Gerling et al. (2014) experimented with game adjustments, such as score multipliers, the precision of input movements or the amount of movements each player had to perform, which were implemented in a dancing game. Altimira et al. (2014) studied the multiplayer balancing effects of playing digitally augmented table tennis, which encouraged the more skilled player to either play defensively or aggressively.

Another approach, which focuses on the individual gameplay and flow experience of a single player, is the psychophysiological, dynamically adaptive method. Cardano et al. (2016) developed the exergame “Exerpong” and investigated how physiological response can be modulated through in-game parameters. Mueller et al. (2012) implemented real time heart rate balancing in a remote jogging application, because it allows players to focus on their own fitness levels while still engaging with another person. Although current literature shows that there are already numerous insights into DGB- and DDA-strategies available, the especially promising approach of dual flow-based exergame design has not yet been fully exploited. Our work aims at bridging this gap with a comprehensive approach in both research and development, in order to make an innovative and sustainable contribution to the improvement of physical activity experience and to encourage children and young adolescents to become further engaged in healthy physical activity.

4.4 Research-Based Development of Plunder Planet

Based on our player-centered design model for psychophysiological adaptive exergames (2014) and related research and development work, we developed “Plunder Planet”, applying a user-centered design process (Martin-Niedecken & Götz, 2016). “Plunder Planet” is a psycho-physiologically adaptive fitness game environment for children and young adolescents.

Currently, two different single-player input devices are used to physically control the exergame: In one game setup, the player uses the specifically developed full-body motion controller (FBMC), which provides six large buttons, positioned around the player’ s moving area. The player navigates by jumping up and down and hitting buttons. The FBMC offers haptic feedback, and demands coordinative and cognitive skills (Figure 1). In the other setup, and as a contrast to the FBMC, we implemented the commercially available, gesture-based Kinect2® sensor (KIN), which allows for higher freedom of movement (Figure 2). The player navigates by predetermined and free movements (e.g. pushing the arms forward, jump and squat). In both game setup versions, the player’ s objective is to steer a flying pirate ship.

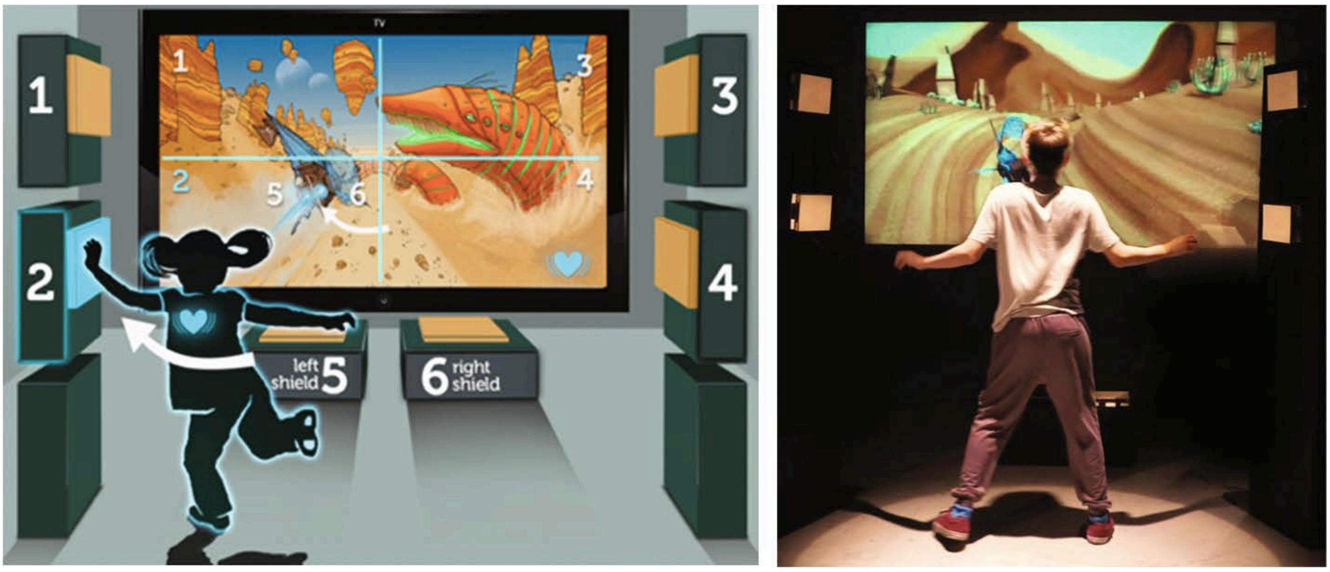

Figure 1: “Plunder Planet” FBMC-setting.

We also implemented three adaptive game mechanics: one targeting the more physiological dimension of the game, and two others focusing on the more psychological aspects.

- During a “Plunder Planet” session, the player wears a Polar H7 sensor which measures the player’s heart rate (HR). The Trainer-GUI offers the possibility to gradually adjust the frequency of obstacles in real time in order to reach the optimal physical level of challenge for each player. The optimal training level for each player/sports type (health zone, fat burning zone, aerobic and anaerobic zone) can be ascertained by calculating the individual maximum HR (HR_{max}; Robergs & Landwehr, 2002):

$$HR_{max} = 220 - age$$

- The in-game performance is assessed by the amount of collisions, successfully overcome obstacles and opponent attacks defended. As a result, the track varies between easier or harder layouts. Also, overcoming obstacles can become easier or harder. Again, the cognitive level of challenge can be gradually adjusted via Trainer-GUI.

Figure 2: “Plunder Planet” Kinect-setting.

For all variables, the quality of adjustment features three independent levels of difficulty (low, medium and high, and each with three to four sub-levels: 0.0–0.3, 0.4–0.6, 0.7–1). Thus, the game difficulty and complexity can be adapted to the current physical, cognitive and emotional state of the player in real time.

In our previous feasibility study (Martin-Niedecken & Götz, 2016) we focused on the evaluation of “Plunder Planet” in a manually adaptive condition. We investigated the impact of two different controller devices (FBMC and KIN) on the gameplay experience as well as the spatial presence experience of children and young adolescents. Participants reported positive gameplay/spatial presence experiences and felt very motivated by the game. All participants enjoyed the audio-visual appearance and the story of the game, as well as the implementation of different controller devices.
Additionally, we drew inferences on the effectiveness of the exergame workout based on the analysis of various in-game events, which were tracked during each session. We found that the average HR lay between 125–145 beats per minute (bpm) for the FBMC and 130–160 bpm for the KIN-setup after a play session of 40 min. Thus, children worked-out within the “fat burning zone” (60–70% of HR_{max}) and the “aerobic zone” (70–80% of HR_{max}) (Robergs & Landwehr, 2002), while in both setups none of them realized the effective duration of the training session.

4.5 Evaluation

In an advanced study, we deepened the approach of our previous feasibility study. We wanted to prove whether the adaptive "Plunder Planet" version provides benefits compared to the non-adaptive version (independent variable) regarding "GameFlow", dual flow, motivation, enjoyment and spatial presence, as well as the physiological response (HR) of children and young adolescents (dependent variables). Additionally, we investigated the impact on the player's experiences caused by playing both versions with two different controller devices (independent variable).

4.6 Method

4.6.1 Participants and Procedure

We recruited 54 children and young adolescents (30 males and 24 females) with and without experience of playing video games (28 GX and 26 nGX), and who did or did not frequently enjoy athletic activities (28 A and 26 nA). The age of the participants ranged from 10 to 14 years (M=12.26 years, SD=1.28). For the intervention, participants with GX and nGX as well as with A and nA were divided into two groups: 27 children and young adolescents were assigned to the KIN-group and 27 were assigned to the FBMC-group. The groups did not switch between the two controller versions. All participants remained with the controller version they were assigned to. Both groups can further be divided into four sub-groups (7 GX/A, 7 GX/nA, 7 nGX/A, 6 nGX/nA).

Each exergame setup was played twice, once in the adaptive and once in the non-adaptive condition. To balance sequence effects, half of each group started the session in the adaptive condition, while the other half started in the non-adaptive condition. Every session took four minutes. Before we began data collection, all participants were briefly introduced to the schedule and the idea of "Plunder Planet". Every participant then played one "Plunder Planet" session in order to become familiar with the game and with the respective controller. Participants were treated in accordance with the Declaration of Helsinki (World Medical Association, 2011).

4.6.2 Pre-Classification Guideline

During the familiarization session we pre-classified the individual dual flow-range for each participant, following an explorative guideline: The pre-classification started in the "low level" (0.1–0.3; warm-up level). If the player performed correctly (without in-game collisions) for about 10–20 s, the difficulty and complexity of the gameplay were increased by 0.1–0.2 sub-levels. This procedure was repeated until the player performed almost correctly (up to max. five collisions) for about one minute. Then the upper flow-threshold was reached. To verify the lower flow-threshold, the difficulty and complexity level needed to be carefully reduced for 0.1–0.2 sub-levels every 20–30 s. Again, this procedure was repeated until the player performed collision-free. The range between the lower and upper flow-threshold could then be defined as an individual dual flow-range.

4.6.2.1 Adaptive Condition

The adaptive condition started at the "low level" (0.1–0.3; warm-up level). Within two minutes the level of the adaptive condition was gradually increased until the pre-defined individual dual flow-range was reached. The principal investigator could then operate dynamically within this range via Trainer-GUI for the remaining two minutes. Both the psychological and the physiological game mechanics can be adjusted independently within the predetermined range. For example, it was possible to continue challenging the fitness-related physical skills of the player while the cognitive load was reduced during a short interruption of the player's attention span (e.g. higher frequency of obstacles, but less stressful layout variations of the track). Conversely, the more cognitive and emotional challenge could remain on a high level while the physical difficulty needed to be reduced if the HR of the player was too high (e.g. less obstacles, but a more challenging layout of the track). The division into more psychological and more physiological game mechanics allows for the accurate setting of the individual perfect training mode.

4.6.2.2 Non-Adaptive Condition

By contrast, the non-adaptive condition followed the approach of commercially available exergames, which mostly provide predetermined difficulty levels ("beginner", "advanced" and "expert" level). After a short warm-up phase, the challenge is gradually increased until the level reaches its climax. The level structure is not specifically matched with the player's physical capacity and gaming skills. For this study, we therefore provided a fixed average level of challenge (corresponding to the "advanced" level) without precise adjustment opportunities. Accordingly, and to keep the adaptive and the non-adaptive conditions comparable, the non-adaptive condition started at the "low level" (0.1–0.3; warm-up level). Within two minutes, the difficulty level in the non-adaptive condition continuously increased until it reached its climax. The fixed level of challenge then lasted for the remaining two minutes of the session. Based on the findings of our feasibility study, the fixed maximum difficulty and complexity level for the non-adaptive KIN version was set at 0.6 and 0.7 for the non-adaptive FBMC version.

4.6.3 Data Collection

After each of two completed runs, participants were asked to answer questions which were derived from Sweetser and Wyeth's "GameFlow" model" (Sweetser & Wyeth, 2005; Kliem & Wiemeyer, 2010), applying a 6-point scale (from 1="I do not agree at all" to 6="I fully agree"). Additionally, participants were asked to answer questions about their dual flow experience, enjoyment, motivation and spatial presence, again applying the 6-point scale. Furthermore, every three seconds, HR, in-game performance (in-game events and related in-game actions) and difficulty level of all players and play sessions were recorded.

4.6.4 Statistical Analysis

For statistical analysis IBM SPSS 24 was used. We created a scale by calculating the mean of all "GameFlow" items, "challenge", "concentration", "skills", "control", "clear goals", "feedback" and "immersion". As the reliability of this scale could be improved by removing "challenge", we created a reduced scale and analyzed both, the reduced "GameFlow"-scale and "challenge" as a dependent variable. Furthermore, we conducted analyses on "motivation", "overload", "underload", "optimal challenge", "enjoyment", "spatial presence" and the average "HR". The differences between the FBMC- and KIN-controller versions, the four sub-groups (GX/A, GX/nA, nGX/A, nGX/nA) and the two play conditions (adaptive and non-adaptive) are evaluated in the framework of a repeated measurement ANOVA, with two between factors with two and four levels, and one within factor with two levels. In addition to the p-values, we report effect size η^2. In order to correct for multiple testing, we perform a Bonferroni α-correction and compare the nominal p-values with α divided by the number of comparisons. Instead of $\alpha=0.05$, we use $\alpha_{corrected}=0.05/27=0.002$.

4.7 Results

For all "GameFlow" items ("concentration" , "skills" , "control" , "clear goals" , "feedback" and "immersion" ; Table 1), there is a highly significant difference between the KIN- and the FBMC-version with a higher mean in the FBMC-version ($p<.0005$). "GameFlow" is rated significantly higher in the adaptive condition ($p<.0005$). There is no significant difference between the four sub-groups ($p=.176$).

Table 1: Overall "GameFlow" without Challenge

Influence factor		M	Std. error	p-value	Partial η^2
Controller	FBMC	5.26	0.049	<0.0005	0.416
	KIN	4.87	0.049		
Condition	adaptive	5.38	0.033	<0.0005	0.972
	non-adaptive	4.74	0.038		
Sub-groups				0.176	0.101

For "challenge" ("To me the challenge of the game was…"; Table 2) there are no significant differences between the KIN- and the FBMC-version. The mean of "challenge" is higher in the nonadaptive condition (p=.007). Additionally, we found a significant difference between four groups (p=.001) with the highest valuation of challenge in nGX/nA (M=5.54, SEM=.131) and the lowest in GX/A (M=4.79, SEM=.121).

Table 2: "Challenge"

Influence factor		M	Std. error	p-value	Partial η^2
Controller	FBMC	5.26	0.088	0.583	0.007
	KIN	5.19	0.088		
Condition	adaptive	5.11	0.067	0.007	0.150
	non-adaptive	5.34	0.081		
Sub-groups				0.001	0.296

For "optimal challenge" ("Did you feel optimally challenged by the game?", Table 3) the difference between both controllers is not significant (p=.053). The mean "optimal challenge" is significantly higher in the adaptive condition (p<.0005). There is no significant difference between the four sub-groups (p=.36).

Table 3: Dual Flow "Optimal Challenge"

Influence factor		M	Std. error	p-value	Partial η^2
Controller	FBMC	4.518	0.092	0.053	0.079
	KIN	4.259	0.092		
Condition	adaptive	5.333	0.076	<0.0005	0.963
	non-adaptive	3.443	0.065		
Sub-groups				0.360	0.067

For "overload" ("Did you feel overchallenged at some point while playing the game?", Table 4) there are no significant differences between both controller versions (p=1.0). The mean for "overload" is significantly higher in the non-adaptive condition (p<.0005). There is no significant difference between the four groups (p=.194).

Table 4: "Dual Flow Overload"

Influence factor		M	Std. error	p-value	Partial η^2
Controller	FBMC	2.247	0.108	1	0
	KIN	2.247	0.108		
Condition	adaptive	1.286	0.087	<0.0005	0.797
	non-adaptive	3.208	0.120		
Sub-groups				0.194	0.097

For "underload" ("Did you feel underchallenged at some point while playing the game?", Table 5) we found a significant difference between the two controller versions (p=.001) with a higher mean in the FBMC version. "Underload" was valued significantly higher in the non-adaptive condition (p<.0005). There is no significant difference between the valuation of "underload" for the four sub-groups (p=.057).

Table 5: "Dual Flow Underload"

Influence factor		M	Std. error	p-value	Partial η^2
Controller	FBMC	2.438	0.089	0.001	0.214
	KIN	1.991	0.089		
Condition	adaptive	1.199	0.053	<0.0005	0.852
	non-adaptive	3.229	0.079		
Sub-groups				0.057	0.149

For "motivation" ("Did the game motivate you to be physically active?", Table 6) there is no significant difference between the controller versions (p=.043). The mean of "motivation" was significantly higher in the adaptive condition (p<.0005). There is no significant difference between the four sub-groups (p=.874).

Table 6: "Motivation"

Influence factor		M	Std. error	p-value	Partial η^2
Controller	FBMC	5.292	0.110	0.043	0.086
	KIN	4.967	0.110		
Condition	adaptive	5.5	0.078	<0.0005	0.783
	non-adaptive	4.759	0.088		
Sub-groups				0.874	0.015

For "enjoyment" ("Did you enjoy the game?", Table 7) we found a highly significant difference between the KIN- and the FBMC-version with a higher mean in the FBMC-version (p<.0005). The mean "enjoyment" was significantly higher in the adaptive condition (p<.0005). There is no significant difference between the four sub-groups (p=.123).

Table 7: "Enjoyment"

Influence factor		M	Std. error	p-value	Partial η^2
Controller	FBMC	5.339	0.076	<0.0005	0.427
	KIN	4.708	0.076		
Condition	adaptive	5.497	0.048	<0.0005	0.949
	non-adaptive	4.551	0.064		
Sub-groups				0.123	0.117

For "spatial presence" ("Did you feel immersed into the game?", Table 8) the difference between the controller versions is not significant (p=.868). The mean of "spatial presence" is significantly higher in the adaptive condition (p<.0005). There is no significant difference between the four sub-groups (p=.119).

Table 8: "Spatial Presence"

Influence factor		M	Std. error	p-value	Partial η^2
Controller	FBMC	5.158	0.088	0.868	0.001
	KIN	5.137	0.088		
Condition	adaptive	5.708	0.062	<0.0005	0.847
	non-adaptive	4.586	0.080		
Sub-groups				0.119	0.118

For average “HR” (Table 9) there is a highly significant difference between the KIN- and the FBMC-version ($p<.0005$). For KIN the mean of HR was 145 bpm while it was 135 bpm for the FBMC-version. The means of the adaptive and the non-adaptive condition are identical. There is a highly significant difference between the four sub-groups ($p<.0005$) with the highest HR in GX/nA (M=146.14, SEM=1.49) and the lowest HR in nGX/A (M=135.96, SEM=1.49).

Table 9: “HR”

Influence factor		M	Std. error	p-value	Partial η^2
Controller	FBMC	134.99	1.073	<0.0005	0.488
	KIN	145.05	1.073		
Condition	adaptive	140.03	0.861	0.961	0.000
	non-adaptive	140.01	0.709		
Sub-groups				<0.0005	0.373

4.8 Discussion, Conclusion and Outlook

Generally, “Plunder Planet” received very good valuations for “GameFlow”, “dual flow”, “motivation”, “enjoyment” as well as “spatial presence” by all study participants. The adaptive game version achieved significantly higher rankings by the test persons than the non-adaptive version. Thus, the general hypothesis, that individually balanced exergames hold benefits compared to non-adaptive exergames, can be confirmed for “Plunder Planet”. Regarding the effectiveness of “Plunder Planet”, we found similar HR values for the adaptive and the non-adaptive condition. Average HR values in both cases result from three “Plunder Planet” sessions (twelve minutes) and fall within the “fat burning zone” (60–70% of HR_{max}). Considering the short time frame this can be seen as a very good result. We found a tendency towards better ratings in the FBMC-version for all “GameFlow” items and “enjoyment”. This result confirms our controller design decisions.

To conclude, the presented study suggests that “Plunder Planet” is a scientifically approved tool which provides attractive and effective training. Thus, it can help children and young adolescents to prevent childhood obesity and excess weight in a playful way.

Our future work will focus on the implementation of further adaptive game mechanics (e.g. audio-visual style, story, etc.). We also aim to derive an algorithm for individual game balancing and automate the adaption process during the “Plunder Planet” session. Simultaneously, we want to continue experimenting with different controller types (e.g. haptic, gesture-based, mixed reality, etc.), which can also be integrated into the dynamic game adjustment approach (e.g. changing the position of a button dependent of the player’ s performance). Regarding the in-game and controller-based balancing mechanisms, we want to experiment with body-movement variations.

4.9 Acknowledgment

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4.10 References

Altimira, D., Mueller, F., Clarke, J., Lee, G., Billinghurst M., and Bartneck C. (2016). Digitally Augmenting Sports: An Opportunity for Exploring and Understanding Novel Balancing Techniques. In Proceedings of the Conference on Human Factors in Computing Systems (CHI '16), ACM, New York, NY, 1681-1691.

Altimira, D., Mueller, F., Lee, G., Clarke, J., Billinghurst, M. (2014). Towards understanding balancing in exertion games. In: Proceedings of the 11th Conference on Advances in Computer Entertainment Technology (ACE 2014), pp. 1–10. ACM, New York.

Bianchi-Berthouze, N. (2013). Understanding the role of body movement in player engagement. HCI, 28(1): 40- 75.

Cardona, J., Cameirao, M., Paulino, T., Badia, S., Rubio, E. (2016) Modulation of Physiological Responses and Activity Levels during Exergame Experiences. In Proceedings of the 8th International Conference on Games and Virtual Worlds for Serious Applications (VS-Games), IEEE, 1-8.

Csikszentmihalyi, M. (1990). Flow. Harper Collins Publishers, New York.

Fery, Y.A., Ponserre, S. (2001). Enhancing the control of force in putting by video game training. Ergonomics 44(12), 1025-1037.

Gerling, K.M., Miller, M., Mandryk, R.L., Birk, M. and Smeddinck, J.D. (2014). Effects of Balancing for Physical Abilities on Player Performance, Experience and Self-esteem in Exergames. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14), ACM, New York, NY, 2201-2210.

Harris, K., Reid, D. (2005). The influence of virtual reality play on children’s motivation. Can. J. Occup. Ther. 72(1), 21-29.

Kim, S.Y.S., Prestopnik, N. and Biocca, F.A. (2014). Body in the interactive game: How interface embodiment affects physical activity and health behavior change. Computers in Human Behavior 36: 376-384.

Kliem, A., Wiemeyer, J. (2010). Comparison of a traditional and a video game-based balance training program. Int. J. Comput. Sci. Sport 9(2), 80-91.

Martin, A.L. & Kluckner, V.J. (2014). Player-centred Design Model for psychophysiological adaptive Exergame Fitness Training for Children. In Proceedings of the Games for Health Europe Conference 2014 (GFH Europe '14), 105-109.

Martin-Niedecken, A.L. and Götz, U. (2016). Design and Evaluation of a Dynamically Adaptive Fitness Game Environment for Children and Young Adolescents. In Proceedings of the Annual Symposium on Computer- Human Interaction in Play (CHI PLAY '16), ACM, New York, NY, 205-212.

Mazzeo, D., Arens, S.A., Germeroth, C., Hein, H. (2012): Stopping childhood obesity before it begins. SAGE: Phi Delta Kappan 93(7), 10–15.

Mueller, F., Vetere, F., Gibbs, M., Edge, D., Agamanolis, S., Sheridan, J. and Heer, J. (2012). Balancing exertion experiences. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12), 1853-1862.

Murphy, E.C., Carson, L., Neal, W., Baylis, C., Donley, D., Yeater, R. (2009). Effects of an exercise intervention using Dance Dance Revolution on endothelial function and other risk factors in overweight children. Int. J. Pediatr. Obes. 4(4), 205–214.

Nijhar, J., Bianchi-Berthouze, N. and Boguslawski, G. (2011). Does movement recognition precision affect the player experience in exertion games? In Camurri A., Costa C. (eds.) INTETAIN 2011. LNICST, Vol. 78, Springer, Heidelberg, pp 73-82.

Oh, Y., Yang, S. (2010). Defining exergames and exergaming. In: Proceedings of Meaningful Play, pp. 1–17.

Osorio, G., Moffat, D.C., Sykes, J. (2012) Exergaming, exercise, and gaming: sharing motivations. Games Health: Res. Dev. Clin. Appl. 1(3), 205–210.

Pasch, M., Bianchi-Berthouze, N., van Dijk, B., Nijholt, A. (2009). Movement-based sports video games: investigating motivation and gaming experience. Entertain. Comput. 1(2), 49–61.

Robergs, R.A. & Landwehr, R. (2002). The surprising history of the „HR_{max}=220-age“ equation. Journal of Exercise Physiology online, 5(2), 1-10.

Sohnsmeyer, J. (2011). Virtuelles Spiel und realer Sport – Über Transferpotenziale digitaler Sportspiele am Beispiel von Tischtennis (Virtual games and real sport–About the transfer potentials of sport games using the example of table tennis), Hamburg, Czwalina.

Sohnsmeyer, J., Gilbrich, H., Weisser, B. (2010). Effect of a six-week-intervention with an activity promoting video game on isometric muscle strength in elderly subjects. Int. J. Comput. Sci. Sport 9(2), 75-79

Sinclair, J., Hingston, P. and Masek, M., (2007). Considerations for the design of exergames. In Proceedings of the 5th international conference on Computer graphics and interactive techniques in Australia and Southeast Asia (GRAPHITE '07), 289-295.

Skalski, P., Tamborini, R., Shelton, A., Buncher, M. and Lindmark, P. (2010). Mapping the road to fun: Natural video game controllers, presence, and game enjoyment. New Media & Society 13, 2: 1-19.

Stach, T. & Graham, N.T.C. (2011). Exploring haptic feedback in exergames. In Proceedings of the Conference on Human- Computer Interaction (INTERACT '11), 18-35.

Sweetser, P. & Wyeth, P., (2005). GameFlow: a model for evaluating player enjoyment in games. Computers in Entertainment 3(3), 3-3.

Wiemeyer, J., Temper, L. (2017). Edutainment in sport and health. In: Nakatsu, R., Rauterberg, M., Ciancarini, P. (eds.) Handbook of Digital Games and Entertainment Technologies, Springer Science + Business Media, Singapore, 883– 908.

Weibel, D. & Wissmath, B. (2011). Immersion in computer games: The role of spatial presence and flow. International Journal of Computer Games Technology, Article No. 6: 1-14.

World Health Organization. http://www.who.int/dietphysicalactivity/childhood/en/
World Medical Association (1991). Declaration of Helsinki. Law, Medicine & Health Care, 19, 264- 265.

5 Manuscript III: Designing for Bodily Interplay: Engaging with the Adaptive Social Exertion Game "Plunder Planet"

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Author Contributions:
Anna Lisa Martin-Niedecken is the initiator of the presented work and sole author of the paper. She was responsible for the conception, design and conduction of the study, the co-development of the exergame, the analysis and interpretation of the data and writing of the manuscript.

5.1 Abstract

Among younger people, game-based group workouts have become very popular. Thus, as design resources, the social settings become as important as the technology. However, there is still limited knowledge about how to exploit the full design potential of bodily interplay in social exertion games and how technology can be used as a social exertion "shaper" rather than a "limitation". To contribute to this topic, we present a multiplayer version of our adaptive exergame "Plunder Planet". It can be played with two controllers demanding either haptic or gesture-based input movements. We conducted a study and investigated the social and bodily potential of our game. Playing the game with both devices supported good social gameplay experiences. The haptic device supported a greater feeling of empathy and engagement. Children's preferred version and employed play strategies depended on their skills/preferences in sports and gaming. Results help identify design approaches for future social exertion games.

5.2 Introduction

Body-centered exergames, interactive training systems and gamified group workouts for single and multiplayer/team athletes have become one of the hippest and most successful trends in today's fitness and gaming sector. Especially younger users, so-called "digital natives", engage, either alone or together with others, with multimodal sensor technologies, which demand specific coordinative and cognitive abilities and exercise-related body movements (Oh & Yang, 2010). The users' physical inputs are directly transferred and projected onto further interactive technology (e.g. LED lights or a screen), which provides audio-visual, haptic and/or narrative feedback to the athletes. In combination with a playful framework created by either a virtual game scenario immersing the player in a "magic world" or by a trainer acting as "game maker", this results in a training/gaming experience which is very attractive and effective. There are many variations of this innovative training method: exergames and playful training setups are available for the living room (e.g. Nintendo® Wii or Microsoft Kinect for Xbox®) as well as for the gym (e.g. Embedded Fitness). Furthermore, there is an increasing trend towards multiplayer exergames and playful group workouts (e.g. Immersive Fitness by Les Mills or Prama's Pavigym). For the young generation, this is the future way to keep fit, healthy and socially connected at the same time. Thus, as design resources, the social settings become as important as the technology (Marquez Segura eta l., 2013), the body (e.g., Marquez Segura et al., 2013) and the virtual game scenario (e.g., Martin-Niedecken, 2017).

Although there are various solutions available, there is still limited knowledge about how to exploit the full design potential of bodily interplay in social exertion games. Current solutions often lack a user-centered, symbiotic design approach covering the physical and virtual (social) level. Full-body motion game controller technologies in particular are criticized quite often because they tend to limit the range of body movements and to inhibit social dynamics as well as bodily interplay in multiplayer exergames (Marquez Segura et al., 2013; Benford et al. 2005; Loke et al. 2007).

In order to contribute to this debate and put forward suggestions for designers of future social exertion games, we approach the topic from two sides. Firstly, we present a cooperative multiplayer version – developed on the basis of research – of our adaptive exergame "Plunder Planet". We provide insights into the design process of the cooperative social exertion game version for two players and contextualize our design decisions in a theoretical framework on bodily interplay dimensions in social exertion games by Mueller et al. (Mueller et al., 2017). Secondly, we present a study, which we conducted to evaluate these design decisions and to explore the potential of our specifically designed and/or implemented game controller technology to act as a bodily interplay and social exertion game experience "shaper". We investigated the effects of different motion controllers on the gameplay and social presence experiences of children and young adolescents with diverse sports and gaming experiences as they were playing our adaptive social exertion game "Plunder Planet".

Additionally, we conducted participatory observations during the multiplayer sessions to obtain a deeper understanding of the specific communication and movement strategies of the players. Finally, we derive recommendations from the results, which should help designers of future social exertion game systems to exploit the full potentials of bodily interplay in social exertion.

5.3 Related Work

Since exergaming has become a successful and certified trend (e.g., Mueller et al., 2017) in the gaming, health and fitness sectors, designers and researchers have been searching for new ways to enhance these playful workout experiences even more. Various studies provide insights into the effects of specific body movements (e.g., Pasch et al. 2009), controller technologies (e.g., Shafer et al., 2014) as well as adaptive game mechanics and other aspects of design (e.g., Cardona et al. 2016) on the player's gameplay/training experience (e.g., (dual) flow or immersion), and propose specific frameworks (e.g., Martin & Wiemeyer, 2012) or design guidelines (e.g., Mueller et al., 2011). However, these approaches focus on single or dual design dimensions rather than the symbiotic combination and the evaluation of the interplay of all three exergame dimensions. Consequently, insights from these studies remain limited although they hold important indicators for designers of future exergame developments. The same applies to the approach of user-centered design methods (e.g., Hanington & Martin, 2012) in exergame developments (e.g., Gerling et al., 2010). Many existing exergame solutions did not involve the intended target group(s) in the design process, although we already know that personal preferences and characteristics as well as creative input of the user group hold important information and tremendous potential for the design process.

The issues described above become even more important in the context of the parallel trend of playful group fitness training. Depending on their personal preferences and disposition towards team or individual sports, many children and young adolescents favor group workouts for motivational and social reasons. This also applies to exergaming and exergame fitness training. Thus, when it comes to the development of so-called "social exertion game" settings (Mueller et al., 2017), as design resources, the social settings become as important as the controller technology (Marquez Segura et al., 2013), the body (Marquez Segura et al., 2013), and the virtual game scenario (Martin-Niedecken, 2017).

Today, numerous multiplayer games allowing "social play" are already available. According to Isbister (2010), social play is the active engagement with a game by more than one person. Playing together results in a completely different gameplay experience than playing alone. From a game research perspective on game design in general, we know that in contrast to solo play, social play can positively influence gameplay experiences. Players of multiplayer games more often experience less tension, greater competence (e.g., Gajadhar et al., 2008) and less frustration (e.g., Mandryk et al., 2006). When it comes to multiplayer exergames, there is a variety of other, additional effects. Social exergaming is proven to increase self-efficacy (Peng & Crouse, 2013; Chin et al., 2008), intrinsic motivation (Staiano et al., 2013; Lubans et al., 2008), prosocial behaviors (Granic et al., 2014; Coyne et al., 2011) and continued gameplay (Chin et al., 2008). That is because more than one player is involved, with their whole body, in the gameplay. The players' bodies and "bodily interplay" (Mueller et al., 2017) become an important regulator for gameplay experiences and social presence in exergames.

According to Mueller et al., bodily interplay refers to the extent to which bodies can act on and react to each other. Inspired by the work of Frost et al. (2008) they propose viewing bodily interplay as a spectrum of dimension, which means that players can experience anything from "none" to "a lot" of bodily interplay. Bodily interplay can be divided into two categories: "parallel exertion" and "interdependent exertion". Parallel exertion describes experiences in which people partake in an exercise together, but act independently (e.g. 100-meter race), while interdependent exertion describes experiences in which people can actively use their bodies to physically act interdependently (e.g. basketball). Mueller et al. further formulate sub-categories along the bodily interplay dimensions for the physical and the virtual game space:

Parallel exertion: "knowing" (players are aware of each other's bodily actions), "comparing" (players compare each other's actions), "matching" (players match the other player's rhythm and move synchronously).

Interdependent exertion: "shared object" (players share the same object and physically have an effect on each other's exertion actions), "shared space" (players physically influence the other players as to how they use their bodies), "shared bodies" (players use their body to directly control the other player' bodies).

Finally, Mueller et al.'s framework (Mueller et al., 2017) provides design suggestions for bodily interplay in the physical and the virtual social exertion game space and four ways of coupling both spaces ("comparative", "actuated", "derived", and "projected coupling") by following body-centered and technology-centered design approaches.

Comparative Coupling games offer parallel exertion in the physical and the virtual space. Therefore, neither the players' nor their avatars' bodies can interact with one another. This coupling supports the comparison of exertion between players although players might easily turn into a solitary rather than a social experience. Thus, Mueller et al. (2017) suggest implementing more symbolic (getting their meaning from mental associations with other symbols) and indexical representations of exertion (having an actual connection such as correlation in space and time with the exertion) beside the more common implementation of iconic representations (resembling exertion activity like an avatar representing the player's movements) into social exertion games. According to Mueller et al. (2017), due to comparative data and immediate feedback, players can calibrate their physical effort within their own effort range and with respect to that of their opponent/co-player. Thus, comparative coupling often results in calibrating experiences for the players.

Actuated Coupling games offer parallel exertion for the player in the physical space while the player's avatar acts interdependently. Actuated couplings could be enhanced by the implementation of tactics like offensive and defensive play, without needing to be concerned about body contact. To keep the initial tight coupling between the player and his/her avatar, Mueller et al. (2017) recommend the implementation of iconic and indexical representations of exertion in the virtual space. Actuated coupling games very often result in a channeling experience/attention of the player to the mediating virtual representation.

Derived Coupling games offer interdependent exertion in the physical and parallel exertion in the virtual space and are less commonly found. The challenge is to create a successful mix of parallel and interdependent aspects while ensuring a meaningful play experience. Mueller et al. (2017) suggest implementing symbolic representation strategies to enhance parallel exertion. Derived coupling games often lead to contributing experiences.

Projected Coupling games offer interdependent exertion in the physical and the virtual space. Players need to pay close attention to both spaces and coordinate their actions in each space with respect to the other one (coordinating experiences). Mueller et al. (2017) recommend the implementation of force feedback technology as the coplayer's opportunity to affect one's avatar should be ideally linked back to one's body via tight coupling.

In the commercial market and in the academic exergame field, we find numerous multiplayer exergames, which approach the topic of social play in various ways (e.g., Gerling et al., 2014). However, most of the existing multiplayer exergames only allow players to interact independently and side by side without directly sharing a common gameplay experience. Full-body motion game controller technology, which was not sufficiently body- and user-centered designed, is very often criticized as being the reason for these limitations. It is often implied that technology in exergames and social exertion games “instrumentalizes” the body too much (Höök et al., 2016), that it narrows the possibilities of movement and limits or even eliminates social dynamics (Marquez Segura et al., 2013; Benford et al., 2005; Loke et al., 2007). Players’ interactions are neither cooperative nor competitive in real-time and do not have any direct impact on the gameplay of the other players. Mueller et al. (2017) argue that if there is any bodily interplay while playing these games, this would be incidental rather than integral to the gameplay experience.

There is extensive research and design (R&D) literature and work to draw upon concerning the shaping of rich physical, emotional and social experiences in multiplayer exergames (e.g., Voida et al., 2010; Isbister et al., 2016; Bianchi-Berthouze, 2013). Especially the related work on shaping the physical and emotional player experiences of single players served as a significant basis for our previous R&D work in the field of adaptive and holistic exergames (Martin-Niedecken, 2017; Martin-Niedecken & Götz, 2016; Martin-Niedecken & Götz, 2017). For the further R&D work presented here, we were inspired by the framework by Mueller et al. (2017) since we were particularly interested in the exploration of specifically developed game controller technologies as social exertion and bodily interplay “shaper”, allowing for multiple parallel as well as interdependent exertion experiences and thus to exploit the full design potential of a social exertion game.

To sum up, and as already stated by other researchers (e.g., Marquez Segura et al., 2013; Benford et al., 2005; Mueller et al., 2017), current commercial technologies often present limitations on bodily interactions that could be easily supported and would allow players to experience a wider range of social play interactions. Furthermore, there is a knowledge gap regarding the structures of bodily interactions in social play, and thus only limited knowledge on how to design for them, especially when the aim is to ideally target as many different player and sports types as possible.

5.4 Research-Based Design of “Plunder Planet“

Based upon the variety of concepts and theories relating to the design levels of the virtual game scenario (e.g., Voida et al., 2010), the controller setup (e.g., Shafer et al., 2014), and body movements (e.g., Bianchi-Berthouze, 2013), we created “Plunder Planet” (Martin-Niedecken & Götz, 2016), a dual flow-based, psycho-physiologically adaptive fitness game environment for children and young adolescents. According to the dual flow concept (Sinclair et al., 2007), an optimal training/gameplay experience during exergame play requires a balance between the game related challenge and player skills, as well as between the intensity of the required movement input and the player’s fitness level.

5.4.1 Single Player Version

Originally, “Plunder Planet” was developed as an adaptive single player fitness game environment for children and young adolescents (Martin-Niedecken, 2017; Martin-Niedecken & Götz, 2016; Martin-Niedecken & Götz, 2017). Design work was symbiotically implemented at all levels: the virtual game scenario, the game controller setting and the body movements. We involved children and young adolescents aged 10 to 14 years, with and without skills in gaming and sports, and with different preferences in gaming (single or multiplayer games) and sports (single or team sports), in the design process of the exergame. All intermediate stages were repeatedly tested, evaluated and modified based on the results until the final game scenario was completed. We employed several user-centered design methods (Hanington & Martin, 2012) such as interviews, guided sketching as well as discussing style and story-mockups.

The final scenario of “Plunder Planet” draws the player into the world of a young pirate, searching for buried treasures on an abandoned desert planet, with a flying pirate ship. The aim is to get as many points as possible. Therefore, the player has to collect crystals, avoid collisions with obstacles and fight off attacks of giant sandworms. During a “Plunder Planet” session, the player wears a Polar H7 sensor, which measures the heart rate (HR). To provide a dual flow-based gameplay/training experience, we adapted the difficulty (frequency of obstacles) and complexity level (track varies between easier and

more challenging layouts and overcoming obstacles can become easier or harder) of the game to the player's current HR and in-game performance.
In close collaboration with experts from the fields of sports science as well as industrial and interaction design, a specific full-body motion controller (FBMC) was iteratively developed to further support the dual flow and immersion experience of the player, and also to enable cognitive and coordination training. "Plunder Planet" can currently be played with two controller variants: beside the specially developed FBMC (Figure 1, left) which challenges the player's cognitive and coordinative skills, and offers haptic feedback through the use of buttons, we also implemented the gesture-based Kinect® sensor (KIN, Figure 1, right) which allows for higher freedom of movement and in principle enables more natural or intuitive movements. In relation to the design and implementation of the controllers as well as the game scenario, we further explored various body movements as input movements, in consultation with sports scientists and the target group.

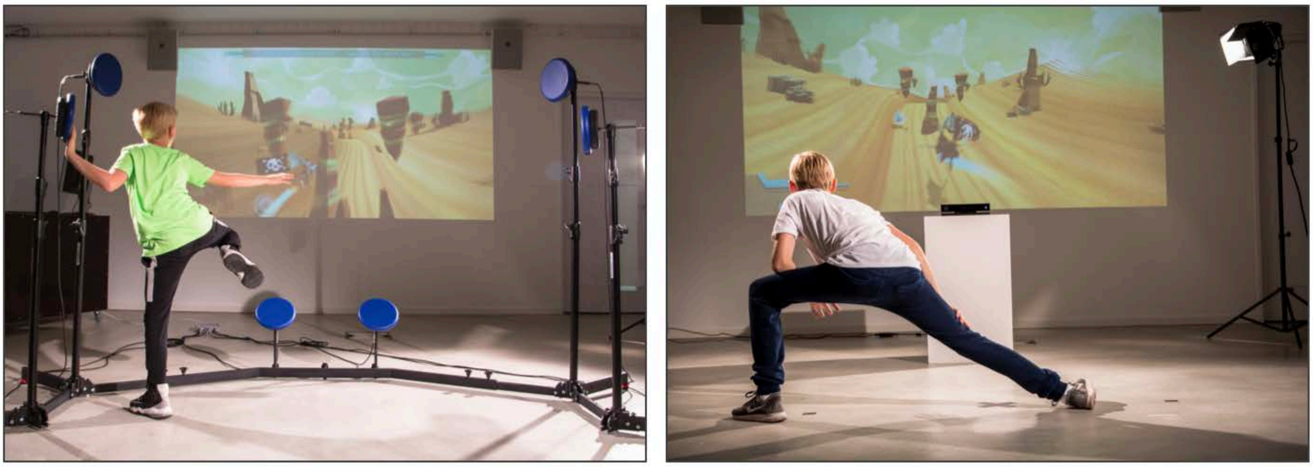

Figure 1: Single Player FBMC (left) & Kinect version (right).

Figure 2: Multiplayer FBMC (left) & Kinect version (right).

The FBMC is controlled by pushing six buttons in the direct vicinity of the player's body and/or exercise space. The buttons are located at three heights (high, middle and low) to the left and right of the player. The player has to jump dynamically between the buttons in order to press these at the right moments. The height and distance of the buttons can be adjusted to the size of the player. In order to avoid virtual obstacles, the player must hit the middle and upper buttons on the right or the left, while the two lower buttons (one on each side) serve to activate shields to protect the player from giant sandworms. In the meantime, the FBMC has been further developed following the same principles as the previous prototype. The KIN is also operated through six movements on three levels. To avoid collisions with obstacles, the player must either jump or duck to the left or the right as the situation requires. The shields are activated by extending the left or the right arm to the front.

5.4.2 Multiplayer Version

After we successfully proved the feasibility and usability of the adaptive single player KIN and FBMC version of "Plunder Planet" (Martin-Niedecken, 2017; Martin-Niedecken & Götz, 2016; Martin-Niedecken & Götz, 2017), we showcased both setups at numerous official exhibitions. Very soon it became clear that the exergame held immense potential to be extended as multiplayer versions. Visitors to the exhibitions started playing the FBMC version on their own initiative and intuitively with two to six players. The only rule we set was that users were only allowed to push the buttons with their hands and not with their feet. We were able to observe various groupings: children playing with other children or with their parents and grandparents. Each group developed its own communication and control strategies to successfully play together. These findings inspired us to deepen the multiplayer approach for two players. We decided to do the obvious and followed the approach of a cooperative multiplayer version of "Plunder Planet". We consolidated our R&D work with the theoretical framework of bodily interplay dimensions and applied related suggestions by Mueller et al. (2017).

On the design level of the virtual game scenario and the adaptive game mechanics, we did not change anything. Players share one screen and navigate the flying ship (shared object) together. In terms of body movements and the game controller we implemented slightly new designs and rules. While playing the multiplayer version of "Plunder Planet" players are co-located in the same physical space: either in the "free" motion space with the KIN version or in the motion space surrounded by six buttons with the FBMC version. Inspired by the observations of visitors we made with the exhibitions and Mueller et al.'s design recommendations for bodily interplay (Mueller et al., 2017), we experimented with various control strategies by taking the existing input movements of the single player setups and developing them further for two players. For the FBMC, we ended up dividing the controller space into two halves (Figure 2, left). Both players stand side by side in the middle of the button setup, which can be flexibly and independently adjusted in width and height although two players playing together may be differently sized. One player is responsible for the right and the other for the left side of the controller setup (shared physical object). Players each operate with three buttons (one on the lower level, one in the middle and one at a higher level) and navigate the flying ship together (shared virtual object/shared body). They have to push the upper and the middle buttons to overcome obstacles and the lower buttons to activate the shields to defend against sandworms (iconic and indexical representations of exertion). The same applies to the KIN version (Figure 2, right). Players navigate one ship together, this time by sharing the "free" and gesture-based motion space. Again, they are standing side by side in front of one screen. One player is responsible for the right-sided control movements and gestures and the other player for the left-sided ones. In contrast to the FBMC version, players jump up or squat down to overcome obstacles and, instead of pushing buttons, push their arms forward to activate the shields (iconic and indexical representations of exertion). Both setups incorporate a balanced mix of more interdependently exertion-driven actuated, derived and projected couplings and some more parallel exertion-driven comparative coupling moments in both the physical and the virtual game space of "Plunder Planet". Players' movements are a direct response to the physical and virtual movements of their co-players and/or their respective in-game actions with the ship. For example, one player jumps up and pushes the upper button to overcome an obstacle, and the other player has to activate the shield directly afterwards, because there is a sandworm attacking the flying ship directly behind the obstacle. Thus, players are aware of each other and have to move immediately and proactively with only very short time frames between the single movements. To ensure a successful cooperative in-game performance and to avoid solitary play experiences, players have to communicate with each other, coordinate their input-movements and make sure their timings are accurate. If they do not have an interdependent movement strategy and, for example, each push a right- or left-sided button at the same time, the ship will collide with the obstacle, which is a typical comparative coupling moment. Conversely, there are also unplanned moments when, for instance, both players activate the shields and together fend off a sandworm attack (iconic and indexical representations of exertion), which results in a very strong joint team experience due to an actuated coupling. Sharing one controller setup further adds partly comparative coupling moments to this experience, because it also enables each player to collect crystals independently from his/her coplayer (although the amount of all collected crystals is crucial for the score). Since there is direct feedback provided by the virtual scenario (e.g. colliding with an obstacle resulting in a deduction of points; symbolic representation of exertion) players always know how well or poorly they are performing. They can compare their performance with each other and, if necessary, calibrate their physical and cognitive effort to the level which best relates to the level of the co-player, and thereby experience a successful collaborative, contributing and channeling performance. These effects are positively influenced by the adaptive game adjustment – the optimal challenge level and the accompanying guidance of both players towards each of their dual flow states (Sinclair et al., 2007) – which is based on the players' average HR and in-game performance.

5.5 Study: Evaluating Bodily Interplay and Social Exertion in "Plunder Planet"

5.5.1 Multiplayer Study

Our previous studies provided a "proof of concept" and explored the role of technology as dual flow and spatial experience- "shaper". The presented study follows the results of our previous R&D work (Martin-Niedecken, 2017; Martin-Niedecken & Götz, 2016; Martin-Niedecken & Götz, 2017) and investigates the further development of "Plunder Planet", which, in addition to still being playable as an adaptive single player fitness game, can now also be played as a cooperative social exertion game by two players using again the KIN version and a further developed prototype of our FBMC. The main foci of this study were i) the evaluation of our new social exertion game design decisions, which were mainly implemented at the level of the controller and bodily interplay as well as ii) the investigation of the potential of both controller technologies to act as social "enabler", "supporter" and "shaper". Therefore, we investigated the following main research questions (RQs):

- **RQ1:** Are there any differences in the valuation of social presence experience with each controller setup?
- **RQ2:** Are there any differences in the valuation of gameplay experiences with each controller setup?
- **RQ3:** Are there any differences in the valuation of gameplay experiences when playing a single and a multiplayer version of "Plunder Planet" with the same controller setup?
- **RQ4:** Which communication and bodily interplay/movement strategies did players develop while playing the multiplayer version of "Plunder Planet"?

All RQs must be investigated in relation to participants' skills in gaming and sports, playing with two different devices, playing the single or multiplayer version of "Plunder Planet", participants' personal preferences regarding gaming and sports, as well as taking into consideration participants' gender and sex, since these subcategories may have additional impact on the valuation of social presence and gameplay experiences.

5.5.2 Participants

Participants were recruited at several official exhibitions of "Plunder Planet" where parents of interested children could sign up their children to be invited for the actual study. All potential participants were asked to provide information about their previous gaming and sports experience, their personal preferences in gaming and sports, as well as their age and gender when joining the participant recruitment list. For the study, we invited N=32 children and young adolescents (16 males and 16 females) with and without experience in playing video games (16 GX and 16 nGX), and who did or did not frequently enjoy sports activities (16 A and 16 nA). Participants were divided into four main groups (8 GX/A, 8 GX/nA, 8 nGX/A, 8 nGX/nA) with an equal gender distribution (4 males and 4 females per group). Each main group was further divided into four teams of two. The teams were paired based on an equal or mixed "gender-specific composition", meaning being paired in same-sex or mixed-sex teams (subgroup 1: m/m, f/f, m/f), "personal gaming preferences", meaning the preference for and skills in single player games, multiplayer games or neither (subgroup 2), and "personal sports preferences", meaning the preference for and skills in individual sport, team sport or neither (subgroup 3). Participants did not know their teammate before the study started. They were introduced to each other by the principal investigator before they were playing together. The age of the participants ranged from 10 to 14 years (M=11.91 years, SD=1.28). Participants were treated in accordance with the Declaration of Helsinki (World Medical Association, 1991).

5.5.3 Procedure and Data Collection

Participants were briefly introduced to the study procedure and how to play the single as well as the multiplayer version of "Plunder Planet" together with their teammate. All boys and girls were at least a little bit familiar with the single player version of "Plunder Planet" because they had played it earlier at the official exhibitions. To balance sequence effects, two teams of each main group started playing the KIN version, while the other half started playing the FBMC version. For both versions participants started playing the single player condition of "Plunder Planet" first before they played the multiplayer condition together with their teammate. Each gaming session took four minutes. After two completed runs the team changed over to the other controller setting and the whole procedure was repeated. To add a little extra challenge and incentive to the whole study setting, the final scores of the multiplayer teams were put on a highscore board, which was visible to all participants.

After playing the single player condition of "Plunder Planet", participants were asked to answer the "Kids Game Experience Questionnaire" (KidsGEQ) (Poels, et al., 2008) regarding their gameplay experiences, applying a 5-point Likert scale (from 0=I do not agree at all to 4=I fully agree). They then played the multiplayer condition of "Plunder Planet" together with their teammate and again were asked afterwards to fill in the KidsGEQ and additionally answer questions from the "Social Presence Experience Questionnaire" (SPGQ) (de Kort et al., 2007), again applying a 5-point Likert scale concerning their social presence experience.

Furthermore, participants both wore a Polar® H7 sensor during the single as well as the multiplayer sessions. To provide a dual flow-based gameplay/training experience in both settings, we adapted the difficulty and complexity level of the game to the current physical responses and to the in-game performance of the players. Within the single player version, we adjusted the more physiological challenge to the HR of the player and the emotional and cognitive challenge to the player's in-game performance. Within the multiplayer version, we took the average HR of both players and adapted the more physiological challenge to these measures. The emotional and cognitive challenge was adapted in the same way as in the single player version.

Additionally, we conducted participatory observations during the multiplayer sessions to obtain further insights into the bodily interplay and social exertion play strategies of the players. Two researchers (1 male and 1 female) observed communication and movement strategies of participants during the multiplayer sessions with the KIN and FBMC versions following pre-defined guidelines, which were developed partly on the basis of Mueller et al.'s bodily interplay dimensions (Mueller et al., 2017):

- **General team dynamics:** How did teammates come to an arrangement with each other? Did players define a specific distribution of roles within the team?

- **Team communication:** How did players communicate with each other? Either non-verbally (e.g. by movements and gestures) or verbally (e.g. by talking, laughing, yelling or cheering)?

- **Bodily interplay:** How did players coordinate physical interaction with each other (in the physical and virtual space)? Were there differences between the teammates? Did they orient themselves towards each other or something else (in the physical and virtual space)?

5.5.4 Quantitative and Qualitative Analysis

We calculated mean scores for all items of the SPGQ and the KidsGEQ. This resulted in three scales ("psychological involvement: empathy", "psychological involvement: negative feeling" and "behavioral engagement") for the SPGQ and seven scales for the KidsGEQ ("challenge", "flow", "competence", "immersion", "negative affect", "positive affect" and "tension"). To ensure a sufficient validity despite the small sample size, we performed a multivariate analysis of variance (MANOVA) with repeated measurements to detect differences, effects and interactions of player group composition, the two controller setups and the single and multiplayer version in both questionnaires. In the MANOVAs the scales of the two questionnaires were modeled simultaneously as dependent variables. We analyzed the effects of one within factor (controller version for the SPGQ and single/multiplayer mode for the KidsGEQ) and four between factors with three to four factor levels (main group, gender-specific group composition, game and sports-specific skill compositions). Additionally, we present explorative results of the univariate analyses of variance (ANOVA), which model only one dependent variable (the scales of the two questionnaires).

In order to correct for multiple testing, we divided the confidence level alpha by the number of effects in the MANOVA with the six SPGQ scales, which were simultaneously modeled as dependent variables. As we examined nine effects, four main effects of the between factors, one main effect of the within factor and four interactions of the between factors and within factor, we used $\alpha corrected=0.05/9=.006$. Thus, in the framework of the MANOVA, we interpreted effects with a p value $<.006$ as significant. P-values cited in the univariate analyses and the correlations are not corrected. These results are explorative.

Participatory observation protocols were analyzed independently by two researchers (1 male and 1 female) following the approach of a qualitative analysis (similar to Mayring's (2010) qualitative content analysis) according to the three categories of our guideline. The individual surveys were compared and in case of a deviation they were discussed to reach a common consensus.

5.6 Results

Below, we report the results for participants' gameplay as well as social presence experience while playing the multiplayer version of "Plunder Planet", and participants' gameplay experience while playing a single player version of "Plunder Planet". Both versions were played with the KIN and the FBMC. Since the focus of this paper is on social exertion play and bodily interplay, we start with the results for social presence experience and follow this with a more explorative interpretation of the gameplay experience.

5.6.1 Correlations

We analyzed correlations between all SPGQ-dimensions for the multiplayer KIN and FBMC versions (Table 1).

There are significant correlations between the scales in respect of the controller version: "Empathy" while playing the KIN version strongly correlates with "empathy" while playing the FBMC version ($r=.671$, $p<.0005$). "Negative feeling" while playing the KIN version strongly correlates with "negative feeling" while playing the FBMC version ($r=.632$, $p<.0005$). "Engagement" while playing the KIN version strongly correlates with "engagement" while playing the FBMC version ($r=.602$, $p<.0005$). Thus, participants who rated social experience better or worse for one controller setup, tended to do so for the other setup as well. In general, there are further strong correlations between social presence experiences with respect to the controller. Only the correlations between "negative feeling" and "engagement" of both controllers are weak to moderate.

Table 1: Correlations between social presence experience dimensions, *p<.05; **p<.01.

	Mean	SD	1	2	3	4	5	6
KIN_Empathy	3.01	.32	-					
FBMC_Empathy	3.40	.324	.671**	-				
KIN_NegFeeling	.21	.21	-.592**	-.574**	-			
FBMC_NegFeeling	.06	.11	-.468**	-.536**	.632**	-		
KIN_Engagement	2.84	.41	.682**	.456**	-.297	-.262	-	
FBMC_Engagement	3.38	.30	.576**	.587**	-.325	-.285	.602**	-

5.6.2 Social Presence Experience

We then analyzed the main effects and interactions of the two controller versions, the main group factor and three subgroup factors. We ran a 4 (main groups) x 2 (controllers) MANOVA with repeated measurements and three 3 (subgroups) x 2 (controllers) MANOVAs with repeated measurements on the last factor: the 4 (main groups) x 2 (controllers) MANOVA with repeated measurements on the last factor revealed a highly significant difference between the KIN version and the FBMC version (factor levels of the within factor) for social presence experience ($F_{3,26}=81.9$, $p<.0005$, partial $\eta^2=.904$). We found a main effect of the main group factor ($F_{9,84}=2.12$, $p=.037$, partial $\eta^2=.185$), subgroup 1 ($p=.193$), subgroup 2 ($p=.004$) and subgroup 3 ($p=<.005$). There are four interactions of main group factors and controller ($F_{9,84}=3.085$, $p=0.037$; partial $\eta^2=.248$), subgroup 1 ($p=.193$), subgroup 2 ($p=.004$) and subgroup 3 ($p<.0005$).

5.6.2.1 Empathy

We further explored the main effects and interactions of controller, main group and subgroup factors by running univariate ANOVAs for each scale of the SPGQ: for "empathy" (example item: "I felt connected to the other player"), the difference between the two controller versions is significant with a higher mean ($M_{FBMC}=3.41$, $SD_{FBMC}=.057$; $M_{KIN}=3.01$, $SD_{KIN}=.056$) in the FBMC version ($F_{1,28}=100.33$, $p<.0005$, partial $\eta^2=.782$). We found a significant interaction of main groups and controller versions ($F_{3,28}=5.553$, $p=.004$, partial $\eta^2=.373$), but there is no significant main effect of the main group. Interaction shows up with better valuations for "empathy" with the FBMC and worse valuations with the KIN for all main groups. The biggest difference can be reported for participants of the GX/A group. Furthermore, there is a significant main effect for subgroup 1 (gender-specific composition). Mixed teams with one male and one female teammate rated best for "empathy" while teams with two males rated worst. We found a significant main effect ($p=.002$) and interaction effect ($p=.002$) for empathy with subgroup 2 (personal gaming preference). Participants who preferred multiplayer games rated better than participants who preferred single player games. In all reported cases, "empathy" was rated better with the FBMC version than with the KIN version. For subgroups 2 and 3 the difference is between valuations for the FBMC and the KIN, which are smaller for participants who had personal preferences for sports and gaming. Finally, we found a significant main effect ($p=.001$) for empathy with subgroup 3 (personal sports preference). Players who preferred team sports experienced better "empathy" than those who preferred individual sports.

5.6.2.2 Negative Feeling

For "negative feeling" (example item: "I tended to ignore the other player"), the difference between the two controller versions is significant with a higher mean ($M_{FBMC}=.06$, $SD_{FBMC}=.11$; $M_{KIN}=.21$, $SD_{KIN}=.21$) in the FBMC version ($F_{1,28}=24.427$, $p<.0005$, partial $\eta^2=.466$). After reversing negative scales, there is no difference or interaction effect between the main groups for "negative feeling". We found a significant main effect ($p=.03$) and interaction ($p=.012$) for subgroup 1. Mixed teams with one male and one female teammate experienced less "negative feelings", whereas teams with two males experienced more "negative feelings". All subgroups of gender specific group compositions reported less "negative feelings" with the FBMC than with the KIN, while the difference was biggest with teams of two males. There was no significant main effect for subgroup 2 while there is a significant main effect ($p=.005$) for subgroup

3. Players who preferred team sports experienced less “negative feeling” while those who preferred individual sport reported stronger “negative feelings”.

5.6.2.3 Engagement

For “engagement” (example item: “The other player’s actions were dependent on my actions”), the difference between the two controller versions is significant with a higher mean (M_{FBMC}=3.38, SD_{FBMC}=.30; M_{KIN}=2.84, SD_{KIN}=.41) in the FBMC version ($F_{1,28}$=153.040, p<0.0005, partial η^2=.845). Participants of the GX/A group experienced the highest “engagement”, whereas participants of the nGX/nA group experienced the least. There are no significant effects of gender-specific group composition (subgroup 1), but with regard to personal gaming preferences (subgroup 2) there is a significant main effect ($F_{3,28}$=9.73, p<.0005, partial η^2=.510) and interaction (p=.032). Participants who preferred playing multiplayer games and participants who had no gaming preference experienced more “engagement” than participants who preferred playing single player games. Participants of all factor levels of subgroup 2 rated better for “engagement” with the FBMC version than with the KIN version. For subgroup 3 there is a significant main effect (p=.002) and interaction effect (p=.022). Participants who had no preference in sports experienced the most “engagement”, whereas those who preferred individual sports, experienced the least. Participants of all factor levels reported more “engagement” with the FBMC version than with the KIN version.

To sum up, the explorative univariate analyses affirm the highly significant difference between the controller versions showing up in all SPGQ scales. Both the interaction of the main groups and subgroup 2 with the controller version manifests itself and can be reported for “engagement” (p<.0005 and p=.032) and “empathy” (p=.004 and p=.002).

5.6.3 Gameplay Experiences

Below, we report the results for the KidsGEQ resulting from playing a single and a multiplayer version of “Plunder Planet” with two different controllers. Since we focused on the differences of gameplay experiences between the two controller setups in previous studies, we decided to examine the differences between the single and multiplayer mode in the presented study. First, we focus on all scales of the KidsGEQ, while we will take a closer look at the “flow” dimension, which is in our case the most important gameplay experience dimension.

5.6.3.1 Gameplay Experiences

When gameplay experiences for the KIN version are rated including the factor of main groups, the difference between the single and multiplayer version is highly significant ($F_{7,22}$=6.414, p<.0005, partial η^2=.671). There is a highly significant main effect ($F_{21,72}$=4.372, p<.0005, partial η^2=.560) and an interaction ($F_{21,72}$=7.011, p<.0005, partial η^2=.672) of the main group factor with the player mode (single/multiplayer mode). There are neither significant effects of subgroup 1 (p=.922) nor main effect or interaction with the player mode (p=.146). Subgroups 2 and 3 show significant main effects and interaction with the player mode (p=.001 and p=.001). When gameplay experiences for the FBMC version are rated including the factor of main groups, the difference between the single player and multiplayer mode is highly significant ($F_{6,23}$=7.919, p<.0005, partial η^2=.674). There is a highly significant main effect ($F_{18,75}$=5.960, p=.001, partial η^2=.589) and an interaction ($F_{18,75}$=2.910, p<.0005, partial η^2=.411) of the main group factor with the player mode (single/multiplayer mode). There are neither significant effects for subgroup 1 (p=.834) and 3 (p=.053), nor main effects or interaction with the player mode (p=.621 and p=.08). For subgroup 2 there are significant main effects and interaction with the player mode (p<.0005 and p=.029).

5.6.3.2 Flow

When the “flow” (example item: “I felt like I was inside the game”) experience for the KIN version is rated including the factor of main groups, the difference between the single player and multiplayer mode is highly significant ($F_{11,28}$=16.661, p<.0005, partial η^2=.373). There is a highly significant main effect ($F_{3,28}$=3.163 p=.04, partial η^2=.253) and an interaction ($F_{3,28}$=14.733 p<.0005, partial η^2=.612) of the main group factor with the player mode (single/multiplayer mode). There are neither significant effects for subgroup 1 (p=.693), nor main effects or interaction with the player mode (p=.566). For subgroup 2 there is a significant main effect and interaction with the player mode (p<.0005 and p=.021) whereas we found a significant interaction for subgroup 3 (p=.001).

Table 2: Descriptive statistics: Means and standard deviations by condition and group; M(SD).

	KIN		FBMC	
	Single player	Multiplayer	Single player	Multiplayer
GX/A	3.8(.37)	2.9(.30)	3.6(.50)	4.0(.20)
GX/nA	3.3(.47)	3.1(.50)	3.3(.50)	3.4(.50)
nGX/A	3.4(.48)	3.3(.50)	3.2(.40)	3.6(.50)
nGX/nA	3.0(.20)	3.1(.40)	3.6(.50)	3.7(.50)

The significant interaction of the main group with the controller version shows up in lower ratings for "flow" by participants of the GX/A group in the multiplayer mode (Table 2). Valuations of participants of the nGX/A and the GX/nA group revealed only marginal differences concerning the "flow" experience with the single and the multiplayer version. The significant main effect for main groups shows up in ratings of participants of the nGX/nA group who reported the weakest "flow" experience and participants of the GX/A group who reported the strongest feeling of "flow". For the valuation of "flow" with the KIN, there are no significant effects of subgroup 1. There is a significant main effect (p<.0005) and an interaction (p=.021) of subgroup 2 for the "flow" experience with the KIN. Participants who preferred multiplayer games experienced better "flow" than participants who did not have a preference in gaming or who preferred single player games. Participants who either preferred single or multiplayer games rated better for "flow" with the single player mode. Participants without any preference for gaming rated "flow" equally for both player modes. There is a significant interaction of player mode and subgroup 3 (p=.001). Participants who either preferred single player games or individual sports rated better for "flow" with the single player mode. Participants without any preference for sports rated "flow" better with the multiplayer mode. When the "flow" experience for the FBMC version is rated including the factor of main groups, the difference between the single player and multiplayer mode is highly significant ($F_{1,28}$=13.843, p=001, partial η^2=.331). There is a significant main effect for main groups ($F_{3,28}$=5.463, p=.004, partial η^2=.369). There are neither significant effects for subgroup 1 (p=.823) and 3 (p=.691), nor main effects or interaction with the player mode (p=.704 and p=.379). For subgroup 2 there is a significant interaction with the player mode (p=.023) whereas we found a significant interaction for subgroup 3 (p=.001). For "flow" there is no main effect for subgroup 3. The significant main effect of the main groups as between factor (p=.004) is caused by the valuations for "flow" by participants of the GX/A group, which were higher than the ratings of the other three groups. For "flow" there are no significant main effects for subgroup 1. There is a significant interaction (p=.023) of subgroup 2. With the FBMC, participants rated the "flow" experience higher in the single player mode.

5.6.4 Participatory Observation

The participatory observation provided further insights into mostly interdependent social exertion play processes and bodily interplay in both multiplayer versions.

5.6.4.1 General Team Dynamics

If one or both teammates belonged to the GX/A or nGX/A group, they came to an arrangement quickly. Mostly, one of the players took the role of the team leader and gave commands throughout the play session (e.g. telling his or her co-player when to push which button). This resulted in very vivid social interactions and sometimes it was not easy for the teammate who was not the team leader to assert him- or herself. Participants of the GX/nA and the nGX/nA groups tended not to have any "fixed roles" within the team. Their communication was more balanced and dynamic. Each of the two players supported their team member with important notes and inputs.

5.6.4.2 Team Communication

In the GX/A and nGX/A teams, we were able to observe verbal as well as non-verbal communication strategies. If players had skills in an individual sport, they tended to “guide”, “support” (e.g. when there was more than one possibility to overcome an obstacle or if one of the players lost the flow of movements), or to “correct” their teammate non-verbally (e.g. by hitting the button themselves if their teammate seemed to miss the right moment). If they had skills in team sports, they more often cheered their teammate and both players laughed together more often. Participants of the GX/nA and nGX/nA teams also communicated in both ways (verbally and non-verbally), but less offensively and in a more game-related way (e.g. some players imitated the sound of the ship sliding over the ground, or made a sound when activating the shields).

5.6.4.3 Bodily Interplay

We observed slightly different movement strategies of the players for both the physical and the virtual space. Participants who belonged to the GX/A and nGX/A group more often oriented themselves towards the controller (in case of playing with the FBMC) or the feedback provided by the ship in the virtual space (e.g. they adapted their movements to the exact movements of the ship). This applied especially to players who preferred playing single player games and like individual sports and resulted in channeling and contributing experiences. If players of the same groups preferred playing multiplayer games and team-sports they oriented themselves much more towards their co-player, beside the controller-device (e.g. players tried to keep up the movement of their co-player to continue the flow). Participants of the GX/nA and the nGX/nA group tended to orientate themselves towards the movements of their co-player and the controller (e.g. if a player was not that good in navigating the ship correctly, they tended to look over to their co-player and tried to imitate their movements). This resulted in contributing and cooperative experiences. In general, we were able to observe that participants with skills in sports effortlessly interacted with the multiplayer KIN version as well as with the FBMC version, whereas participants without any skills in sports interacted more confidently with the multiplayer FBMC.

5.7 Discussion

Following, we summarize our quantitative and qualitative results following our RQs.

RQ1*:* There is a highly significant difference in the valuations of social presence experiences for both controller setups. The feeling of “empathy” was better with the FBMC for all main groups. Participants of all main groups reported less “negative feelings” and more “engagement” with the FBMC version. These results are further emphasized by the findings of the participatory observation. We found that participants tended to be more interactive on the levels of interdependent bodily interplay and communication with the FBMC version.

RQ2*:* In general, we found very good “gameplay experience” valuations for both controller devices. This corresponds with findings from our previous studies (Martin-Niedecken, 2017; Martin-Niedecken & Götz, 2016; Martin-Niedecken & Götz, 2017). However, there are differences between both controller versions, which mainly relate to group-specific characteristics. Findings from the participatory observation confirm these results. Participants with skills in sports easily co-controlled the multiplayer KIN as well as the FBMC version. They quickly adopted the required movements and coordinated these with the movements of their co-player. Participants with skills in gaming tended to be more confident with the FBMC version because of the “physical guidance”, which was provided by the buttons.

RQ3*:* Instead of focusing on all dimensions of gameplay experiences, we decided to particularly focus on the “flow” dimension. For the “flow” experience with the KIN we found highly significant differences between the single and multiplayer mode. Participants of the GX/A group experienced strong “flow” with the single player KIN version whereas participants of the nGX/nA group experienced the weakest "flow" with the same version. For the multiplayer mode, participants of the nGX/A group experienced the best "flow" and participants of the GX/A group the weakest. For the "flow" experience with the FBMC we found highly significant differences between the single player and the multiplayer mode. Again, participants of the GX/A group rated best for the "flow" experience with the single and multiplayer mode. For the single player mode, participants of the nGX/A group experienced the worst "flow" and participants of the GX/nA group experienced the weakest "flow" with the multiplayer mode. Again, findings from the participatory observation confirm these results for the same reasons we described under RQ2.

RQ4*:* Participatory observation revealed that the implemented coupling designs produced the desired effects on players' bodily interplay strategies. In general, participants who belonged to the groups with skills in sports tended to move in a more self- or controller-oriented and offensive way if they preferred individual sports (triggered by comparative couplings) and in a more cooperative and less offensive way if they preferred team sports (triggered by actuated, derived and projected couplings). Participants without skills in sports and participants with skills in gaming tended to move cooperatively and more defensively while strongly orienting themselves towards the controller (triggered by actuated, derived and projected couplings). As we have shown before (Martin-Niedecken, 2017; Martin-Niedecken & Götz, 2016; Martin-Niedecken & Götz, 2017), the "physical guidance" of the FBMC version as well as the "higher freedom of movement" of the KIN version offer the optimal spatial orientation solution for every sports and player type. Furthermore, in our study setting, we found that communication was a strong predictor for bodily interplay (triggered by actuated, derived and projected couplings). Verbal as well as non-verbal communication were used as an additional point of orientation between the players. Comparable to the movement strategies, we found different types of communication depending on the group participants belonged to. Players who had skills in sports communicated more offensively than players who belonged to the group with skills in gaming. For all teams, one of the most "rewarding" or "punishing" moments was the situation when we listed their score on the official high score board. This resulted in intense team dynamics (e.g. shared joy or disappointment depending on the position on the board) as well as calibrating experiences (comparison with other teams).

5.7.1 Recommendations

Based on our presented R&D work, we are able to make recommendations for designers of future social exertion games: concerning the impact of both controller versions on players' social presence experience and their ability to serve as social exertion "enabler", "supporter" and "shaper", we found that both devices caused slightly different experiences as well as bodily interplay and communication strategies, which were further enhanced by players' individual gaming and sports skills and preferences. Thus, for the design of parallel exertion-driven comparative couplings and calibrating experiences, we suggest experimenting with gesture-based controller devices, which allow for a high freedom of movement but do not necessarily support interdependent exertion in the physical game space without additionally set rules and game mechanics. If designers implement more interdependent exertion-driven actuated, derived or projected couplings and intend channeling, coordinative and contributing experiences, they should rather experiment with controller setups demanding haptic input. Furthermore, designers should reach for a balanced/dynamic mix of coupling designs, which match their targeting group's skills and preferences for single/multiplayer gaming and individual/team sports.

5.7.2 Limitations and Future Work

In the presented work we mainly focused on technology mediated bodily interplay rather than on dynamic game balancing for social exertion play. Thus, to further contribute to existing R&D work on these topics, our future work will also focus on the implementation of further adaptive game mechanics shaping social exertion play and bodily interplay. Furthermore, we plan to implement a competitive multiplayer version, which can be played with both controller setups (one to two players playing with the FBMC against one to two players playing with the KIN).

5.8 Conclusion

To sum up, we have contributed to the current debate on the potential of social exertion games on several levels. Firstly, we exemplarily incorporated existing theories and input of the target group into the design of a multiplayer version of the adaptive fitness game environment “Plunder Planet”. Secondly, we evaluated our design decisions. We were able to prove the usability and functionality of “Plunder Planet” as a social exertion game. Contrary to many statements of related work (e.g., Marquez Segura et al., 2013; Benford et al., 2005; Loke et al., 2007), we can clearly state that specifically designed controller technology can be used as “enabler”, “supporter” and “shaper” of bodily interplay for various sports/player types in social exergaming. We provide a useful test example of how different controllers can be used to shape social presence experience by overcoming technical and user-specific limitations on bodily interactions. Finally, we provided recommendations for designers of future social exertion games.

5.9 Acknowledgments

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5.10 Selection and Participation of Children

We involved children and young adolescents aged 10 to 14 years, with and without skills in gaming and sports in the narrative and audio-visual design process of the exergame “Plunder Planet” as well as in the presented multiplayer study. Participants were recruited at several official exhibitions of “Plunder Planet” where parents of interested children could sign up their children to be invited for the presented study or for the participation in the iterative design process of the game. Participants were treated in accordance with the Declaration of Helsinki (World Medical Association, 1991).

5.11 References

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

Bianchi-Berthouze, N. (2013). Understanding the role of body movement in player engagement. HCI, 28(1), 40- 75.

Cardona, J., Cameirao, M., Paulino, T., i Badia, S., Rubio, E. (2016). Modulation of Physiological Responses and Activity Levels during Exergame Experiences. In Proceedings of the 8th International Conference on Games and Virtual Worlds for Serious Applications (VS-Games), IEEE, 1-8.

Coyne, S.M., Padilla-Walker, L.M., Stockdale, L., & Day, R.D. (2011). Game on… girls: Associations between co-playing video games and adolescent behavioral and family outcomes. *Journal of Adolescent Health*, *49*(2), 160-165.

Frost, J., Wortham, S. and Reifel, R. (2008). Play and Child Development. Characteristics of Social Play.

Gerling, K.M., Miller, M., Mandryk, R.L., Birk, M. and Smeddinck, J.D., (2014). Effects of Balancing for Physical Abilities on Player Performance, Experience and Self-esteem in Exergames. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14), ACM, New York, NY, 2201–2210.

Gajadhar, B.J., de Kort, Y.A., IJsselsteijn, W. (2008). Influence of social setting on player experience of digital games. In Proceedings of Extended Abstracts on Human Factors in Computing Systems (CHI '08), 3099-3104.

Gerling, K.M, Schild, J. and Masuch, M. (2010). Exergame design for elderly users: the case study of SilverBalance. In Proceedings of the 7th International Conference on Advances in Computer Entertainment Technology (ACE '10), 66-69.

Granic, I., Lobel, A., Engels, Rutger C.M.E. (2014). The benefits of playing video games. Am Psychol, 69, 66-78.

Hanington, B. and Martin, B. (2012). Universal methods of design: 100 ways to research complex problems, develop innovative ideas, and design effective solutions. Rockport Publishers.

Höök, K., Jonsson, M.P. Ståhl, A. Mercurio, J. (2016). Somaesthetic Appreciation Design. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16), 3131-3142.

Ijsselsteijn, W., de Kort, Y., Poels, K. (2007). Digital games as social presence technology: Development of the social presence in gaming questionnaire (SPGQ). In. Proceedings of PRESENCE '07. 1-9.

Ijsselsteijn, W., de Kort, Y., Poels, K. (2008). Development of the kids game experience questionnaire. In Proceedings of the Meaningful Play Conference (Meaningful Play '08).

Isbister, K., Márquez Segura, E., Kirkpatrick, S., Chen, X., Salahuddin, S., Cao, G. and Tang, R. (2016). Yamove! A Movement Synchrony Game That Choreographs Social Interaction. Human Technology, 12(1), 74-102.

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

de Kort, Y. A., IJsselsteijn, W. and Poels, K. (2007). Digital games as social presence technology: Development of the social presence in gaming questionnaire (SPGQ). In. Proceedings of PRESENCE '07. 1-9.

Loke, L., Larssen, A. T., Robertson, T. & Edwards, J. (2007). Understanding movement for interaction design: Frameworks and approaches. Personal Ubiquitous Computing, 11, 8: 691-701.

Maloney, A.E., Carter, B.T., Kelsey, K.S., Marks, J.T., Paez, S., Rosenberg, A.M., Catellier, D.J., Hamer, R.M. and Sikich, L. (2008). A pilot of a video game (DDR) to promote physical activity and decrease sedentary screen time. Obesity, 16(9), 2074-2080.

Lubans, D.R., Foster, C., Biddle, Stuart J.H. (2008). A review of mediators of behavior in interventions to promote physical activity among children and adolescents. Prev Med, 47, 463-470.

Márquez Segura, E., Waern, A., Moen, J. and Johansson, C. (2013). The design space of body games: technological, physical, and social design. In Proceedings of the SIGCHI Conference on Human Factors in computing systems (CHI '13), 336

Martin-Niedecken, A.L. (2017). Exploring Spatial Experiences of Children and Young Adolescents While Playing the Dual Flow-Based Fitness Game "Plunder Planet". In Proceedings of the International Conference on Computer-Human Interaction Research and Application (CHIRA '17), 218-229.

Martin, A.L. & Wiemeyer, J. (2012). Technology- Mediated Experience of Space while Playing Digital Sports Games. International Journal of Computer Science in Sport (International Association of Computer Science in Sport), 11(1).

Martin-Niedecken, A.L. & Götz, U. (2016). Design and Evaluation of a Dynamically Adaptive Fitness Game Environment for Children and Young Adolescents. In Proceedings of the Annual Symposium on Computer- Human Interaction in Play (CHI PLAY '16), ACM, New York, NY, 205-212.

Martin-Niedecken, A.L. and Götz, U. (2017). Go with the Dual Flow: Evaluating the Psychophysiological Adaptive Fitness Game Environment "Plunder Planet". In Proceedings of the Joint Conference on Serious Games (JCSG '17). Lecture Notes in Computer Science, vol. 10622, 32-43.

Mayring, P. (2010). Qualitative Inhaltsanalyse. Handbuch qualitative Forschung in der Psychologie, 601-613.

Mandryk, R.L., Atkins, S. and Inkpen, K. (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), 1027-1036.

Mueller, F., Gibbs, M. R., Vetere, F. and Edge, D. (2017). Designing for Bodily Interplay in Social Exertion Games. ACM Transactions on Computer-Human Interaction (TOCHI), 24, 3: 1-48.

Mueller, F., Edge, D., Vetere, F., Gibbs, M.R., Agamanolis, S., Bongers, B. and Sheridan, J.G. (2011). Designing sports: a framework for exertion games. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, ACM, New York, NY,

Oh, Y., Yang, S. (2010). Defining exergames and exergaming. In: Proceedings of Meaningful Play, pp. 1-17.

Pasch, M., Bianchi-Berthouze, N., van Dijk, B., Nijholt, A. (2009). Movement-based sports video games: investigating motivation and gaming experience. Entertain. Comput. 1(2), 49-61.

Paw, J. M., Jacobs, W. M., Vaessen, P. G. et al. (2008). The motivation of children to play an active video game. J Sci Med Sport 2008; 11, 163-166.

Peng, W. and Crouse, J. (2013). Playing in parallel: The effects of multiplayer modes in active video game on motivation and physical exertion. Cyberpsychology, Behavior, and Social Networking. 16, 6: 423-427.

Poels, K., Ijsselsteijn, W. and de Kort, Y. (2008). Development of the kids game experience questionnaire. In Proceedings of the Meaningful Play Conference (Meaningful Play '08).

Shafer, D.M., Carbonara, C.P. and Popova, L. (2014). Controller required? The impact of natural mapping on interactivity, realism, presence, and enjoyment in motion-based video games. Presence, 23(3), 267-286.

Sinclair, J., Hingston, P. and Masek, M. (2007). Considerations for the design of exergames. In Proceedings of the 5th international conference on Computer graphics and interactive techniques in Australia and Southeast Asia (GRAPHITE '07), 289-295.

Staiano, A.E., Abraham, A.A., Calvert, S.L. (2013). Adolescent exergame play for weight loss and psychosocial improvement: A controlled physical activity intervention. Obesity; 21, 598-601.

Voida, A., Carpendale, S. and Greenberg, S. (2010). The individual and the group in console gaming. In Proceedings of the ACM Conference on Computer Supported Cooperative Work (CSCW '10), 371-380.

World Medical Association. (1991). Declaration of Helsinki. Law, Medicine & Health Care, 19: 264- 265.

6 Manuscript IV: ExerCube vs. Personal Trainer: Evaluating a Holistic, Immersive, and Adaptive Fitness Game Setup

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Anna Lisa Martin-Niedecken was the initiator of this work. She was responsible for the conception, design and conduction of the study and the co-development of the exergame. Elisa Mekler contributed to the study methodology and data collection. Anna Lisa Martin-Niedecken led the writing of the manuscript, supported by Katja Rogers. Together they analyzed and interpreted the interviews, and co-analyzed and -interpreted the quantitative data with Elisa Mekler. Elena Marquez Segura and Laia Turmo Vidal led the video-based interaction analysis and contributed to the writing. All authors contributed to the discussion, and critically reviewed and approved the final manuscript.

6.1 Abstract

Today's spectrum of playful fitness solutions features systems that are clearly game-first or fitness-first in design; hardly any sufficiently incorporate both areas. Consequently, existing applications and evaluations often lack in focus on attractiveness and effectiveness, which should be addressed on the levels of body, controller, and game scenario following a holistic design approach. To contribute to this topic and as a proof-of-concept, we designed the ExerCube, an adaptive fitness game setup. We evaluated participants' multi-sensory and bodily experiences with a non-adaptive and an adaptive ExerCube version and compared them with personal training to reveal insights to inform the next iteration of the ExerCube. Regarding flow, enjoyment and motivation, the ExerCube is on par with personal training. Results further reveal differences in perception of exertion, types and quality of movement, social factors, feedback, and audio experiences. Finally, we derive considerations for future research and development directions in holistic fitness game setups.

6.2 Introduction

For many years now, exertion games in which players exercise in order to play have been embraced by digital native users. Sports science and health-related studies on commercially available and bespoke exergames such as the Nintendo Wii (Nintendo, 2008) confirm the potential of these playful training technologies to increase energy expenditure (Murphy et al., 2009), positively affect learning of sensor-motor and coordinative skills (Fery & Ponserre, 2001; Kliem & Wiemeyer, 2010), strength and endurance (Sohnsmeyer et al., 2010) and exercise program compliance (Harris & Reid, 2005). This multifaceted game genre has also captured attention in HCI (often referred to as exergames (Oh & Yang, 2010), active video games (Bidiss & Irwin, 2020), movement-based games (Mueller & Isbister, 2014) or motion games (Kajastila and Hämäläinen, 2015). Today, exertion games can be played in many contexts (e.g., at home, in public spaces, or the gym), and aim to provide an effective and attractive workout experience for a wide variety of users. The spectrum of playful training solutions thus encompasses a wide range. Exergames like the Nintendo Wii (Nintendo, 2008) are associated with the gaming sector, featuring state-of-the-art game design and controllers, but lack in proper training concepts (Reynolds et al., 2013; Zaczynski & Whitehead, 2014). In contrast, other game-based fitness applications like Technogym Skillrow (Technogym, 2017) clearly belong to the fitness sector, covering professional adaptive workouts and accurate tracking devices, but pay less attention to game design. This bipolar division has been echoed by existing related work in the context of specific sports-based exergames and general exertion games (Isbister, 2016; Kajastila & Hämäläinen, 2015; Marshall et al., 2016; Mueller et al., 2016). The majority of applications lack in focus on the combination of attractiveness and effectiveness; these should be addressed on the levels of players' body (e.g., steering movements based on traditional training concepts), controller (tracking system and interactive hardware), and game scenario (audio-visual appearance, game mechanics, and balancing) following a holistic design approach to establish playful fitness solutions as beneficial additions or alternatives to traditional fitness training.

Towards a better understanding of the interdependent elements of an attractive and effective fitness game, how they impact users' multi-sensory and bodily experiences, and how they can be designed in a holistic manner, we: i) introduce the research-based design of the ExerCube, an immersive and adaptive fitness game setup following a holistic design approach on the levels of body, controller, and game scenario; ii) present findings from a user study comparing the ExerCube with its non-adaptive counterpart and a personal training session, focused on benefits of game adaptivity, and the participants' bodily and multi-sensory (and in particular, auditory) experiences; and iii) derive considerations to inform further development of the ExerCube, as well as future research in holistic fitness game design.

6.3 Related Work

HCI research has often stated the need to re-think exertion game design to better integrate game mechanics and fitness concepts (Isbister, 2016; Kajastila & Hämäläinen, 2015; Marshall et al., 2016; Mueller et al., 2016). Beyond the two extremes of playful training solutions, several applications do successfully incorporate elements from the opposite side (game design or fitness), yet overall their design approach remains closely linked to either game-first (e.g., Beat Saber (Hyperbolic Magnetism, 2018) or fitness-first (e.g., ICAROS (Icaros GmbH, 2018)). Playful training solutions that sufficiently cover both fields of expertise—game design and sports—remain sparse. Two examples of digitally augmented exercise setups have successfully demonstrated benefits of a thoughtful and holistic design approach: ValoClimb, an augmented playful climbing wall (Kajastila et al., 2016) and ValoJump, a game-based trampoline platform (Kajastila et al., 2014). Both developed from research projects into commercially available fitness products, and target one-to-one training of sports-specific movements via respective training devices. For more general full body fitness training, there remains a huge gap.

HCI research and sport science offer numerous guidelines and frameworks aiming for more attractive and effective full-body motion games (Hardy et al., 2015; Hoffmann et al., 2016; Marquez Segura et al., 2013; Marshall et al., 2016; Mueller et al., 2016; Mueller et al., 2014). Insights into player experiences with existing motion-based games yield considerations for their design on the levels of body, controller and game scenario. By designing along these levels in a holistic manner, fitness game setups can achieve an optimal attractive and effective training experience. In the following, we elaborate on selected insights on the three levels in more detail.

6.3.1 Body

In general, the inclusion of holistic physical activity into gameplay is found to be a positive predictor for immersion and engagement (Bianchi-Berthouze et al., 2007). Segura et al. (2013) highlight technological, physical, and social issues that arise during the design process of “body games”, and highlight bodily engagement as a source of enjoyment, and thus an important design resource. Overall guidelines by Mueller and Isbister (2014) suggest embracing movement ambiguity resulting from tracking inaccuracies. Marshall et al. (2016) criticize existing exertion games for a lack of meaningful degrees and nature of body movements, as well as connection of exertion and game design. They propose strategies for the design of exertion trajectories (e.g., create a trajectory across individual play sessions for skill-learning, in consideration of cognitive load and the exertion trajectory), design around pain (e.g., celebrating positive pain), and design for social facets of exertion (e.g., around by-standers). Further, most existing, commercially available exergames for consoles such as Wii Sports (Nintendo, 2006), Wii Fit (Nintendo 2008), and Kinect Sports (Rare, 2010) have been criticized for disregarding performance aspects that are key to successful workouts, e.g., accuracy and precision (Reynolds et al., 2013; Zaczynski & Whitehead, 2014) as well as intensity (Hoffmann et al., 2015). By validating inaccurate movements with successful game performance, these games lack feedback information regarding movement mistakes (Reynolds et al., 2013, Turmo Vidal et al., 2018; Zaczynski & Whitehead, 2014).

6.3.2 Controller

In the context of movement-based games, game controllers have been criticized for limiting bodily design potentials (Marquez Segura et al., 2013) or “instrumentalizing” the body too much (Höök et al., 2005). The same applies to existing products available on the fitness market; the implemented fitness devices act as game controllers, but often lack a meaningful and natural connection between exertion and game design (Marshall et al., 2016). To counteract this problem, Mueller and Isbister (2014) among others suggest incorporating limits of sensor technology as a design resource (i.e., give room for errors). Kim et al. (2014) found that an embodied exergame interface improves user experience, energy expenditure, and intention to repeat the experience. The precision of movement recognition (Nijhar et al., 2012), as well as the natural integration thereof into the game scenario and the related movement feedback are decisive indicators for the “incorporation” of the game controller, and for the immersion into the game world (Pasch et al., 2009). We can clearly identify a need for body-centered controllers that serve as an additional physical playground, easily integrate into players’ body scheme, provide a balance of guided and free movements, and allow for social exertion and social play in cooperative as well as competitive settings.

6.3.3 Game Scenario

The look and feel of immersive, virtual game scenarios for fitness settings should appeal to the target group and involve specific preferences for game mechanics, levels, visuals, sound, and narrative, making it important to involve the target group in the design process from the start (Martin-Niedecken, 2018; Martin-Niedecken & Mekler, 2018). The literature offers suggestions for key elements of the game scenario. For example, games should include immediate celebration of movement articulation, yet also accommodate high cognitive load (especially during learning phases) by providing direct and constrained amounts of feedback (Mueller & Isbister, 2014). Others recommend achievable short-term challenges to foster long-term motivation, and helping players to identify rhythm in their movements, for example by setting movements to specific sound, and visualizing previous and upcoming movements (Mueller & Isbister, 2014; Mueller et al., 2016).

Exergame experiences are closely related to immersion and the experience of flow. Flow (Csikszentmihalyi, 1990) describes the feeling of complete and energized focus on an activity, alongside high levels of enjoyment and fulfillment. A prerequisite to this experience is a match between a person's skills and the challenges associated with their task. Flow has also been defined as a result of immersion or involvement in an activity (e.g., while playing) (Weibel & Wissmath, 2011). In its application to a both physically and mentally challenging exergame, this has been described as "dual flow" (Sinclair et al., 2007). With regards to dual flow, an optimal exergame experience requires a balance between game-related challenge and player skills, as well as between the intensity of required movement input and players' fitness levels. It is thus important that exergames provide an adequate challenge that matches individual skill levels, and their progression over time (Marshall et al., 2016: Mueller et al., 2016).

Game research is increasingly exploring adaptivity as a balancing mechanism (Altimira et al., 2014; Martin-Niedecken & Götz, 2016), to increase engagement and immersion in competitive play (Bateman et al., 2011; Denisova & Crains, 2015; Rogers et al., 2018) and exercise motivation Martin-Niedecken & Götz, 2017). However, how well adaptivity is accepted by players depends on the situation; negative side effects can affect self-esteem (Bateman et al., 2011; Gardner, 1989; Gerling et al., 2014; Vicencio-Moreira et al., 2015). In body-centered games, balancing can keep exertion within a desired range, for example by monitoring heart rate (Hardy et al., 2015; Mueller et al., 2012; Stach et al., 2009). Further, it can be adjusted through internal mechanisms (player-based adjustments, e.g., adding weights to wrists) or external mechanisms, i.e., environment-based adjustments (e.g., changes to the physical location, social factors such as the opponent, or the mechanics and components of the game setup) (Altimira et al., 2014).

6.3.4 Audio in (Exer-)Games

As the impact of audio in exergames has not yet been examined in detail, but has been shown to affect athlete's motivation and performance in sports (Karageorghis & Priest, 2012), we present this aspect separately. In traditional games, audio is used to support cognitive appraisal and hide the medium (Ekman, 2008). Background music (BGM) in particular facilitates immersion, but can also decrease it (e.g., when unsuitable) (Ekman, 2013). While BGM is perceived less consciously than visuals, it affects engagement and immersion, and through these, flow and presence (Berndt & Hartmann, 2008). Specific attributes (e.g., speed) can improve player performance, control, and flow, yet adverse effects are speculated to occur when music overshadows sound effects (SFX), by impairing feedback functionality (Cassidy & MacDonald, 2010; Gasselseder, 2014; Jørgensen, 2008).

In the context of exergames, there are few empirical studies with suitable sample sizes that show beneficial effects of music on performance and gameplay experiences, although guidelines for increasing motivation in exergames have listed music as a requirement (Yim & Graham, 2007). One notable example showed an increase in running performance, however the music was overlaid with motivational commands, making it difficult to pinpoint the cause (Soltani & Salesi, 2013). Another example revealed that exergame music had an impact on some gameplay experience dimensions (Wiemeyer, 2013). Outside of games, the effects of music during exercise are promising but sometimes show mixed results. A review of the literature in the context of traditional exercise (without videogames) has concluded a number of ergogenic and psychological benefits of music for endurance-based exercise, particularly a reduction in perceived exertion (Karageorghis & Priest, 2012). However, evidence varies particularly for higher intensity exercise; it is speculated that physiological processes override sensory distraction provided by music; further, effects appear to decrease for trained athletes.

In mixed reality games, audio is said to be crucial, due to its medium-masking attributes (Larsson et al., 2010). It has been shown to affect presence in VR (Cummings & Bailenson, 2016; Larsson et al., 2010). Yet in modern VR games, audio beyond what is necessary for user feedback (i.e., ambient noises and BGM, as opposed to feedback-based SFX) is perceived less prominently, possibly due to the greater impact of the sensory experience as a whole, as well as novelty bias (Rogers et al., 2018). Thus, for mixed-reality exergames, audio may be particularly important in masking perceived exertion, but its effects might also be overpowered by the sensory whole body experience.

6.4 ExerCube

The ExerCube (Figure 1) is a holistic, immersive, and adaptive fitness game setup, aimed for use in gyms in the near future. It was developed in an iterative research-based design process by an interdisciplinary team of sport scientists, game designers, and HCI researchers in close collaboration with the target audience: adults between ±18–50 years of age who are open towards new technology (Martin-Niedecken & Mekler, 2018). The development followed a threefold holistic design approach, consisting of the levels of the player's body (steering movements based on a functional training concept), the controller (tracking system and interactive hardware), and the virtual game scenario (audio-visual appearance, game mechanics and balancing). Each design level was created in heavy dependence of the others, and by taking into account potential interdependencies of experiences with single or multiple levels of the playful system (e.g., the hardware supports intense physical interactivity, but also provides a playful experience). The ExerCube design was informed by related research and development, as well as by field research in training concepts and fitness gaming. For this paper, we tested the third iteration ExerCube prototype, which will be further developed based on the results.

Figure 1: The ExerCube vs. Personal Trainer.

6.4.1 Body

The ExerCube follows a full-body workout concept that challenges motor-cognition and coordination, at the same time allowing for a playful and dynamic bodily experience for various player and fitness skill types. Its multipurpose functional training concept incorporates natural feeling movements which can easily be transferred to in-game steering (Marshall et al., 2016). Functional training is well known for its overall training effects of increasing endurance, strength, and flexibility (Weiss et al., 2010). It has been defined as emphasizing multiple muscle and joint activities, combining upper and lower body movements, and utilizing more of the body in each movement (Brill, 2008).
We implemented six dynamic movement levels which gradually guide the player through a training progression that is meaningful in the context of movement science, and includes a warm-up phase (levels 1+2) followed by an intensity increase to players' individual anaerobe to high intensity training peak (levels 3 to 6) based on players' individual motor-cognitive and -coordinative skills:

- **Level 1:** Lateral shuffle-step with extension or flexion of the body to the upper, middle, and lower sections of the side walls with touch of the wall + squat (1 min).

- **Level 2:** Level 1 + basic jump (1 min).
- **Level 3:** Level 2 + lateral rotation to the middle of the right and left wall with punch into the wall (2 min).
- **Level 4:** Level 3 + deep lunge with knee bend to the front left and front right with punch into the side walls (2 min).
- **Level 5:** Level 4 + squad jump forwards (2 min).
- **Level 6:** Level 5 + burpee (2 min).

6.4.2 Controller

The HTC Vive system was used to track players' movement and body position. Players wear two HTC trackers, attached to their wrists with a specifically developed mount. The Vive cameras track players' arm positions in relation to their spatial position in the ExerCube and the pre-set targets. Players also wear a heart rate (HR) sensor during the play session. To create a virtual and physical fluently interconnected play space, we designed an open cube-like trapeze (hereafter referred to as "cube"), which physically immerses the player without isolating them, serving as part of the game controller (haptic device) and as a projection screen (interface). The cube measures ~9m2 (length open end: 3.50m; length front wall: 2.60m x height: 2.90m; straight line depth: 2.50m). It consists of a solid steel frame covered with wooden plates. To provide an engaging haptic and tactile experience, the wooden plates are coated with a bouncy foam material, allowing players to punch the walls. The transition of the front to the side walls is slightly curved, to generate a flowing and immersive form. Three projectors are mounted on the frame above, and project the game scenario onto the walls of the cube (Marshall et al., 2016; Mueller & Isbister, 2014). The projection can adjust the play space size to players' height (i.e., restricting the cube to the front part for smaller players).

6.4.3 Game Scenario

The audio-visual appearance and theme of the ExerCube were inspired by individual wishes and preferences of the target audience (Martin-Niedecken & Mekler, 2018). First, the player is guided through a movement tutorial in a virtual training room. Next, the first-person single player game takes the player on a rapid sci-fi themed underwater race. The player navigates an avatar on a hoverboard, speeding along a racing track and passing by various differently colored gates. Each gate features a colour-coded game element relating to a specific functional workout movement. Shortly before the player passes through a yellow or red gate, the gate rotates towards the right or left to provide a target on the wall which the player needs to either touch or punch at the target position. Red gates further provide obstacles that players can overcome by jumping, or squatting low. The game interface displays the number of successfully overcome gates (combos) as a score. As soon as players make a mistake, this count resets to zero. Additionally, the track is divided into sections; players get points for successfully completed sections, while points are deducted if the player performs poorly. Players further receive immediate feedback on their performance, through visuals (mistake: graphics turn red; success: coins appear) and audio (see below), corresponding to existing guidelines (Isbister & Mueller, 2015; Yim & Graham, 2007). To provide a learning aid regarding the in-game steering movements, players are guided by a mentor (virtual character in front of them), who disappears after five minutes of playing.

To calibrate individually optimal performance, the ExerCube features an automated yet experimental game adaptivity algorithm (Marshall et al., 2016; Mueller et al., 2016): Game difficulty is adjusted to players' individual game and fitness skills in two ways: speed of race and music is tied to players' HR (pre-set range of HR), while the time frame of gate rotations is related to the number of mistakes made (i.e., players' cognitive and mental focus).

Both game adjustments are gradually adapted independently over all training levels on a 10-point difficulty scale: If a player performs error free for 20 seconds, the cognitive difficulty will increase by

one level until they make three mistakes within 20 seconds, inducing a difficulty decrease by one level. Beyond the gradual progression of training levels, there is no physical difficulty adjustment during the first 1.5 min of the game. Based on players' HR, game speed is then gradually adjusted (HR<150 bpm for 0.5 min: increase speed slightly by one level; HR>175 bpm for 1 min: decrease speed slightly by one level; HR > 190 bpm: decrease speed strongly by two levels).
Since HR is a challenging game balancing parameter, we used a pre-set range of HR which was informed by previous tests with the ExerCube and related work from sport science, including a comprehensive study (Nes et al., 2013) yielding the following formula to calculate age predicted maximal HR: $HR_{max} = 211 - 0.64 * age$. This aligns well with previous studies and meta analyses (Gellish et al., 2007; Tanaka et al., 2001) which suggested similar formulas. Given the mean age of our participants (M=34.45, SD=8.70) and that we aimed at an anaerobe to high intensity training (80 to 90% of HR_{max}), we set the HR target range around HR_{target}=151 to 180 bpm (i.e., based on HR_{max}=189 bpm).
For the study, the ExerCube also has a non-adaptive variant, with static medium physical and cognitive challenge.
The ExerCube audio design covers both feedback-based SFX and BGM, which were specifically developed by a professional sound designer. SFX appear when the player successfully overcomes a gate (combo sound) or misses one (e.g., crashed into obstacle). The atmospheric BGM reflects the underwater scifi theme. Its speed and rhythm are adaptive; with players' higher HR and good in-game performance the music increases in bpm, and becomes more bass-driven.

6.5 Evaluation

Towards a better understanding of the interdependent elements of an attractive and effective fitness game and how they impact users' multi-sensory and bodily experiences, and to examine benefits of adaptivity, we compared the ExerCube with its non-adaptive counterpart and a personal training (PT) session.

6.5.1 Method

The user study was set up as a within-subject experiment with three conditions: The ExerCube with adaptive difficulty, adaptive BGM and feedback SFX; the ExerCube with nonadaptive difficulty, non-adaptive BGM and feedback SFX; and a control group, wherein participants engaged with a professional PT session with only BGM (Figure 1). The same physical exercises and (non-adaptive/adaptive) BGM were featured in all three conditions. In the PT condition, the feedback sounds were replaced by the verbal and physical feedback of the trainer, who reacted with adjustments in training difficulty and complexity to each participant (comparable to adaptive ExerCube session).
The within-subject design facilitated a valid comparison between different conditions, and is commonly used in the fitness/exercise domain (Hamer et al., 2016). Furthermore, we provided participants with a 10–20min break after each condition to ensure resting HR before they started with the next condition.

6.5.2 Participants

The study was originally performed with 60 participants, across whom the counterbalancing was evenly applied. Due to technical difficulties (WiFi), we could only consider the data of 36 to 40 participants (40 participants for the quantitative results, and 36 for qualitative (interviews)). N=40 participants (19 women, 21 men), aged 16 to 62 years (M=34.45, SD=8.70) reported gaming habits diverse in game literacy. All participants engaged in a variety of physical activities to some extent, with fitness classes (n=29) and jogging (n=21) being the most popular. More than half of the participants (n=25) had prior experience with exergames, mostly with the Wii Fit.

6.5.3 Measures

To assess players' experience of flow, we employed Rheinberg's Flow Short Scale (Engeser & Rheinberg, 2008; Rheinberg et al., 2003), which includes the constructs flow (α=0.90) and worry (α=0.77) on a 7-point Likert scale. We also used the scale resulting from the GameFlow model of player enjoyment (Kliem & Wiemeyer, 2010; Sweetser & Wyeth, 2005) to calculate an overall enjoyment score (α=0.68, 7 items on a 6-point scale, including immersion). Additionally, participants were asked to rate a series of single-item measures capturing different aspects of the player experience such as enjoyment, motivation, as well as feeling overwhelming, insufficient, or optimal challenge, as well as a particular focus on how the ExerCube's audio affected their experience.

Qualitative experiences were assessed via semi-structured interviews targeting aspects of all three levels of the holistic approach. Interviews were audio- and all sessions video recorded for subsequent qualitative and interaction analysis.

6.5.4 Procedure

After consent forms, participants provided demographic information and reported sports and gaming habits. Furthermore, we asked them if they had cardiovascular problems, a screening parameter, and whether they worked with individual HR_{max} or other individual HR values. Then they were introduced to the ExerCube by a study investigator in a familiarization phase. Participants who started in the PT condition were also introduced by a study investigator. All participants engaged with all three conditions for 10 minutes each, in counterbalanced order and were looked after by a certified trainer. Each session was video recorded and tracked (logs of in-game performance and HR), and followed by the surveys. At the end, we conducted semi-structured interviews with 36 participants (~25min). Twelve interviews were conducted with two participants at once.

6.5.5 Analysis

The interviews were assessed by two of the authors following an iterative thematic coding approach based on qualitative content analysis (Mayring, 2015), beginning with the levels of holistic design as first categories. For five interviews at a time, the coders individually transcribed and coded the data. In three iterations, the coders discussed emerging results after each set of five interviews until agreement was reached. A codebook was developed based on the third iteration, and used by the coders to individually assess the remaining interviews.

The videos were analyzed by two other authors of this paper following a qualitative analysis approach based on ethnomethodological methods (IA) (Jordan & Henderson, 1995), using concepts from movement analysis (e.g., within Laban Movement Analysis (Loke et al., 2005)), and biomechanics of human movement and anatomy (Calais-Germain, 2007). An initial screening of all videos was performed, to identify salient features, including body orientation and movement patterns, as well as physical interaction with the game interface. The coding scheme then followed major observed patterns across all conditions, including movement trajectories and patterns, gaze orientation, as well as reoccurring interactive strategies during the gameplay. Finally, a focused micro-analysis of a selection of snippets was performed.

The log files are omitted for scope, however we did briefly check the HR variance of some participants in the adaptive ExerCube condition. Over the full session this ranged from 131bpm during the warm-up to 194bpm in the peak exercise level.

6.6 Results

In the following, we report on all quantitative and qualitative results.

6.6.1 Questionnaires

To check whether the three conditions differed in terms of flow, game flow, and worry, we conducted a series of repeated measures analyses of variance (ANOVAs), with Greenhouse-Geisser correction where necessary. All descriptive values and test results are listed in Table 1. The conditions did not significantly differ in experienced flow, overall game flow score, or perceived worry. We explored the immersion item in the game flow survey separately; there was a significant difference between conditions, F-value=6.18, $\eta^2=0.08$ (small effect (Bakeman, 2005)), $p<.01$. Tukey's HSD as a post-hoc test showed the adaptive condition was significantly more immersive than the PT condition ($p<.01$). We also investigated the additional items on the game experience. There was no difference in experienced enjoyment, motivation, or feeling overwhelmed. However, there was a significant difference in optimal challenge, F-value=5.30, $\eta^2=0.06$, $p<.01$. Tukey's HSD showed challenge was rated less optimal in the non-adaptive condition compared to the PT condition ($p<.02$). There was a significant difference in insufficient challenge, F-

value=4.54, η^2=0.06, p<.05. Tukey's HSD showed the non-adaptive condition was rated significantly higher for insufficient challenge than the PT condition (p<.05).
With regards to audio, no significant differences were observed with regards to whether participants were consciously aware of the music during the experience. However, the degree to which the music was remembered by participants varied significantly, F-value=3.7, η^2=0.09, p<.05. Post-hoc analysis revealed that participants thought the music was more memorable in the adaptive compared to the PT condition (p<.05). Regarding the perceived importance of the music for the experience, the ANOVA first indicated a significant difference, F-value=6.82, η^2=0.15, p<.01, however, Tukey's HSD contradicted this. Whether music was perceived as motivating also differed between conditions, F value=2.56, η^2=0.06, p<.001. Compared to the PT condition, music was experienced as more motivating in the adaptive (p<.01) and the non-adaptive condition (p<.001). As SFX were only rated in the ExerCube conditions, we conducted t-tests for dependent samples. No significant differences emerged with regards to whether participants were aware of the SFX, their perceived importance for the experience and whether SFX were experienced as motivating. Overall, music and SFX were rated very favorably, indicating a ceiling effect.

Table 1: Descriptive statistics & ANOVA results; measures with significant difference between conditions after post-hoc tests are indicated with *.

Variable	$M_{adaptive}$	*SD*	$M_{non\text{-}adaptive}$	*SD*	$M_{personal\ training}$	*SD*	F-value (df)	η^2	*p*
Flow	5.62	0.81	5.49	0.9	5.53	1.08	0.3 (78)	.008	.74
Game Flow	4.89	0.47	4.76	0.58	4.94	0.57	2.13 (78)	.05	.13
Worry	2.91	1.61	2.89	1.63	3.25	1.68	2.95 (78)	.07	.06
Immersion	5.68	0.57	5.45	0.82	5.18	0.75	6.18 (78)	.17	.003*
Enjoyment	5.33	0.86	5.45	0.85	5.2	0.85	1.07 (78)	.03	.33
Motivation	5.75	0.54	5.68	0.69	5.55	0.71	1.66 (78)	.04	.2
Optimal Challenge	4.9	1.15	4.83	0.96	5.4	0.78	5.3 (78)	.12	.007*
Feeling Overwhelmed	2.85	1.08	2.7	1.09	2.78	1.31	0.19 (78)	.005	.83
Insufficient Challenge	2.13	1.18	2.4	1.32	1.68	1	4.55 (78)	.1	.01*
Aware of Music	2.18	1.01	2.28	1.01	2.55	1.15	2.58 (78)	.06	.08
Remember Music	4.8	1.84	4.7	1.83	3.95	2.15	3.7 (78)	.09	.03*
Importance Music	5.2	1.91	5.33	1.61	4.3	2.1	6.82 (78)	.15	.003*
Motivation Music	5.18	1.93	5.35	1.59	4.25	2.01	8.01 (78)	.17	<.001*

6.6.2 Interviews & Video Material

In the following, all quotes indicate the participant ID; Table 2 lists the order in which they experienced the conditions. We refer to the ExerCube condition with adaptive difficulty with the subscript "a", the non-adaptive version as "na", and the personal training condition as "p".

Table 2: Mapping of participant IDs to study conditions for example, a*na*p means the participant experienced the ExerCube conditions first – adaptive, then non-adaptive –, followed by personal training (PT).

a • p • na:	P4, P7, P31, P33	na • p • a:	P6, P8, P12, P13, P16, P22, P23, P25, P35
na • a • p:	P1, P3, P30, P32, P36	p • a • na:	P5, P9, P14, P18, P20, P24, P26
p • na • a:	P2, P10, P11, P17, P21, P34	a • na • p:	P7, P15, P19, P28, P29

6.6.2.1 Players' Overall Experience

When participants were asked to describe their most memorable impression, they elaborated on their immersion experience *("totally present in the game world"*–P33), and overall excitement *("full of focus, cognitively as well as physically, on the game, [...] entirely exhausted after a few minutes and full of endorphins"*–P8).

All participants reported that the steering movements felt natural and familiar. From a somatic perspective, we relate this to the kinds of movements and movement qualities of the in-game "everyday actions" (e.g., reaching, ducking, hopping). Nevertheless, participants experienced a strong learning curve with the ExerCube components (steering movements, tracking system and hardware, as well as game mechanics). Especially in their first ExerCube session, some players felt slightly over-challenged during the first minutes (*"didn't really know what I'm doing"*–P17). This was compounded by tracking limitations and issues of communicating timing for steering movements, causing some participants to experience short moments of frustration (*"I was frustrated because it didn't register my movements"*–P32). This is also reflected in the videos through frustration gestures and sounds upon missing a target. However, when considering the overall ExerCube sessions (after the initial learning curve), participants generally felt neither overwhelmed nor insufficiently challenged (*"fit just right"*–P8). Almost all participants indicated an experience of immersion and flow, in particular, losing track of time (*"time flew by [...] a very immersive experience where you really forgot yourself "*–P24 ; *"you have no chance to think of anything but what is coming at you in that moment [...] you lose any sense of time"*–P29) and dissociation (*"you can forget yourself through the game"*–P20). From a somatic perspective, a strong mental focus was observed in the videos in the form of postural readiness, i.e., many maintained a default base posture looking forwards, with slightly flexed knees and elbows.

6.6.2.2 Comparison of Experiences

Particularly with the adaptive condition, most participants experienced optimal challenge and a great feeling of interactivity: *"[a] it got faster and faster [...] that was fun, yeah, it was challenging [vs. na:] was a little boring"*–P15; *"[na:] was sub-challenged [vs. a:] then it got cool [...] there was an improvement"*–P22. In the videos, this was reflected in bodily engagement that evolved as the challenge increased. The readiness poses early in the game (e.g., low positions with flexed knees, gaze on front wall), and strategies to safely score (e.g., waiting on the target ahead of time), progressed to hectic movements, like thrusting jumps from one wall to the opposite, accompanied by laughter or a frustration gestures upon missing a target.

Some explicitly noticed the adaptivity: *"The first time [na] I couldn't do anything, and the second time [a] was great because it was tailored to me."*–P13. They appreciated when the game sped up or slowed down in moments of physical or cognitive over- or underload: *"I noticed that the game got slower and gave me more time to think [...] very pleasant because I needed the time"*–P16; *"it's cooler when it adapts [...] you see I'm getting better somehow, and then the game also gets more challenging"*–P19. Only some participants felt thwarted if the game slowed down, but this frustration then also turned into increased motivation: *"then I'm even more motivated [...] until it works"*–P7.

Several factors emerged as distinct between participants' experience in the ExerCube conditions, and the PT condition. In the following, we report several aspects of our findings in which we observed contrasts between the ExerCube and the PT, following the three mentioned design levels. Contrasting themes are bolded. We begin with the keywords the participants chose to succinctly summarize their experience with each condition, which the differences. For the PT, keywords talked of the focus on feedback (correction), being challenged (pressure, pushed to the limit, drill), personal characteristics that they associated with the trainer (experience, expertise, seriousness), and aspects relating to a social connection (feeling exposed, face to face, you want to please [the trainer]), as well as being motivated through him. For the ExerCube, the most common association was playfulness (most commonly fun, but also play a game), while others referred to absorption (flow, total involvement, loss of time), and potential novelty aspects (curiosity). It showed direct contrasts with workouts (doesn't feel like sport) and the motivation described appeared more intrinsic: no pressure but still willing to perform.

6.6.2.3 Player: Body and Mind

There was a difference in participants' mental focus. In the ExerCube conditions, players were focused on the game (*"you're not explicitly conscious with your body [...] you're more driven by the game"*–P9; *"very clearly only concentrated on the game"*–P33; *"[my focus] was definitely on collecting points"*–P16).

Generally, participants reported experiencing a strong cognitive challenge and were extremely focused and concentrated throughout the ExerCube sessions (*"it keeps challenging you [...] always have to think"*–P31). This relates to the observations of bodily posture readiness explained before. Also, the heightened focus on in-game targets and scoring translated into target-focused movement, consisting of postural and gestural strategies (e.g., double tapping, pressing with two hands, and punching on the walls). These could be understood as strategies to ensure a target is hit. In contrast, in the PT, participants focused on the trainer (see social factors below) or their own body (*"was able to focus more on the body"*–P20; *"more focused on the movement pattern"*–P4).

The difference in mental focus was accompanied by a distinct difference in perception of exertion. Despite clear signs of exertion in the videos, such as panting, and postural cues (e.g., resting hands on hips, or hands on knees while leaning forwards in lieu of a full squat), almost all participants reportedly did not consciously notice the physical exertion during the ExerCube sessions: *"I noticed the physical exertion afterwards, but never during"*–P23. Instead, they perceived the effects of the physical strain (e.g., heavy legs, sweat) only after finishing the game (*"had to physically perform, but didn't notice it at all during, what I noticed is— afterwards when I exited—I was sweating"*–P26). Only a few participants (who were less physically active) perceived indications of physical exertion towards the end of the ExerCube sessions (*"I noticed that I'm not quite fit enough for it"*–P7).

For some, this was an ambivalent experience; despite enjoying that they did not notice the physical exhaustion, some expressed negative connotations since they felt like the missing focus on their movements might have caused posture or execution errors: *"I focused less on my body because I was very concentrated on the game [...] I didn't concentrate on executing it cleanly"*–P16. This indicates that there was a difference in execution of movements. In the videos, this is reflected by more indulgent postures and movements compared to the PT condition. For example, in-game, reaching targets on the side often involved a small transversal motion (few steps), and leaning towards the target from the feet (or one foot) This contrasted with the canonical full transversal motion to the side with shoulder abduction (arm reaching to the side), which movements in the PT condition more closely followed. Both movements and posture during the PT condition were more uniform throughout. In comparison, movements in the ExerCube condition, specially the adaptive one, depended more on other factors, such as how tired the players were, and the difficulty level. In situations of increased speed, players changed some of the earlier target-focused movements and strategies, like waiting for the target while leaning on the wall.

Another prominent difference consisted of social factors, which were more prevalent in the PT condition. The presence of another person as part of the trainer-student relationship induced a variety of feelings: trust and respect (*"feeling secure [...] accompanied one-to-one"*–P9; *"more personal"*–P16), but also a feeling of heightened awareness (*"when I stood across from [the trainer ...] I was very conscious of what I was doing"*–P7). Participants experienced this as a kind of exposure: wanting to do well (*"you want to please"*–P3), but also feeling pressure to do so: *"I felt stressed [...] scared that I do it wrong [...] with a human in front of you it's more important what he thinks of me"*–P26. This strong awareness of the instructor's presence translated into frequent eye contact in the PT videos. Participants would look at the instructor to get instructional cues (e.g., looking at his squat before they would do theirs), learn about the upcoming exercise (e.g., looking at him pointing at the direction of the next movement), or for validation feedback (e.g., looking at him right after they did a squat). In contrast, many participants felt more comfortable making mistakes in the cube (*"less issues having failures in a game"*–P17). Although we often observed signs of frustration when missing targets, participants also took a break at times, letting a set of targets pass without serious attempts to reach them. On the other hand, one participant explicitly disliked the lack of social factor in the ExerCube: *"too anonymous for me"*–P21. It should be noted that the study investigator sometimes provided impromptu verbal commentaries to the player in the ExerCube condition (e.g., warnings, reminders, or tips regarding upcoming targets or actions). Although this only happened occasionally, these resembled instruction cues in the PT.

6.6.2.4 Controller

Tracking System and Hardware. Concerning the HTC Vive tracking, which still had limitations in terms of accuracy, participants noted that a difficulty in understanding the tracking, particularly timing the jumps during the first ExerCube session (*"I would improve the accuracy"*–P25). However, once they got familiar with the system, most participants thought that the game could be controlled well: *"in the beginning it took a moment until you [understood] then it improves"–P14*; *"absolutely [clear]"*–P36. Participants enjoyed being physically immersed in the cube, and experienced it as focusing their attention on being absorbed by the experience: *"you're focused then, in the room [...] I find that important"–P9* and *"you have a world for yourself, you do your own thing"*–P19. Nobody felt constricted by the cube, even those who otherwise suffer from mild claustrophobia: *"you can really move freely"*–P28. Most perceived the space inside the cube as sufficient (*"you have the feeling you're in a huge room"*–P25), although a few mentioned that they would have liked a larger cube still: *"could've almost had a bit more space"*–P36. In comments after the interviews, some participants also compared the ExerCube to prior experiences with VR games, which had felt more isolating to them.

Beside the pleasant mixed reality/spatial experience, participants clearly stated that the haptic interaction with the cube patterns was an essential part of their experience, facilitating enjoyment (*"I especially liked that you didn't have to hold back when you were punching."*–P28) and helping them to feel involved in the interactive experience: *"[made it] not like a movie that elapses."*–P18 and *"it marks the limits and you can go really far. You're much more in [the experience]"*–P19. As such, the cube was also perceived as functioning like a frame of reference: *"it's a reference point [...] where you get feedback, particularly with the punch"*–P31. This ties in with the video observations of target-focused movement, as well as postural and gestural strategies described above (e.g., multiple taps or punching the walls). However, a few participants mentioned a fear of damaging the ExerCube (*"scared of breaking it"*–P4), or injuring themselves (*"scared when leaping forward, that I'd jump into the wall"*–P18).

6.6.2.5 Game Scenario

As mentioned, participants liked the general appearance of the game scenario, and found it overall *"motivating"*–P24. However, they were more focused on the steering (racing track, gates with color codes, movement icons), and the visual and auditory feedback information. Some participants described the strong focus on this information as an effect of the gates' color codes being hard to memorize (*"should be more clearly differentiated"*–P21). Furthermore, the previously mentioned timing issues were often reported for the period in which they played with the virtual mentor in front of them on the virtual track: *"[wanted help with] estimating when to execute the movement"*–P4. They tended to imitate the movements of the virtual figure synchronously, instead of waiting until the target actually arrived, leading to some confusion and frustration: *"I was glad when he disappeared"*–P33; *"more confused [..] thought it was an avatar"*–P3; *"[the mentor] irritated me [...] it was too slow"*–P5. This was also observed in the videos: participants touching the wall where the target will arrive seconds before it gets there, and waiting for it to come. Only some participants found the mentor helpful to familiarize themselves with the movements (*"for the first game I thought he was great"*–P31), while most oriented themselves via the movement icons above the gates instead.

Participants reported orienting themselves towards the auditory and visual feedback to understand how well they performed in each moment (*"[understood feedback] through the red [graphics] and the sound"*–P9). However, several participants missed an overall feedback: *"in sum or the course of it"*–P24; *"I had no comparison"*–P33; perhaps partly because – as shown by the videos – their gaze was often locked to the racing track and did not include the score (displayed in the upper right of the middle screen). This contrasts with the feedback experienced in the PT condition, which was associated with *"corrections"*–P7 and *"more control"*–P23.

6.6.2.6 Role of Audio in the ExerCube

As audio is largely unexplored for mixed-reality playful fitness systems, we report this aspect separately and in detail. The majority of participants reported that music is a powerful motivator for their workouts in general (*"almost the most important [...] the best way to forget myself"*–P20). However, some participants noted that they do not generally listen to any kind of music or sound while exercising (e.g., to better enjoy the calm and nature while jogging, or because they do sports which encourage or enforce silence during training): *"it's meditative, very consciously for myself [focusing on] the body"*–P9, and *"prefer concentrating on my breathing"*–P32.

During the ExerCube sessions, there was a difference in perception between the SFX and the music. Almost all participants consciously perceived the feedback sounds (*"[The SFX], I always noticed those"*–P35; *"the effects were what I paid attention to [...] were extremely memorable"*–P16, whereas not all participants (consciously) perceived the music (*"The music I didn't notice at all. [The SFX] were the only thing I was consciously aware of"*–P29. Some participants' remarks indicate that this may have been influenced by the game's learning curve (i.e., an increased focus on the motor-cognitive stimuli and general game navigation in the beginning): *"in the first round where I think I was more concentrated I was less consciously aware of the music [...] the second round more so"*–P31. By those that did notice the music, it was perceived as motivating (*"motivating, supporting [...] guiding"*–P3 and as a facilitator of immersion and atmosphere (*"transports me into the atmosphere. Without it I would be much more conscious of the movements"*–P8; *"it supports the flow"*–P31). It was also mentioned in the context of supporting rhythm-based movements (*"it keeps you in the movement [...] it keeps in the game"*–P1) and masking outside noises (*"[without it] I would hear voices, I'd hear the tram"–P24*). Some participants enjoyed the specific current music (*"the sound carried you along"*–P36) whereas others asked for faster, louder, more intense music tracks (*"[the music] didn't touch me [...] want something melodic [with] more push, more power"*–P6). Further, when asked, most participants reported that they would like the option of selecting their own music, although several emphasized that the SFX should remain, and a few expressed worry that self-curated music would not suit the game setting and atmosphere.

If participants did not consciously perceive the music and were told about it during the interview, they were often convinced that they did not realize it because the music perfectly matched and blended into the game scenario (*"probably because it was so [...] not distracting I didn't perceive it"*–P7). Many participants could roughly remember the music (e.g., melody, rhythm, etc.), but a few of them found it difficult to remember anything music-related: *"without the music it's not the same, but I didn't perceive the music, it was there for sure, I heard that, but what it sounded like, no idea, I couldn't tell you"–P28*). Almost all participants—even those that did not consciously perceive the BGM—stated that they thought the experience would be lacking something if the music had been absent: *"probably [would have noticed absence of music]. I think it does help to get in the flow"*–P32. Despite the variance in music perception, some participants nevertheless noticed that the music adjusted to their performance during the adaptive ExerCube session. Some players realized that the game speed was changing through changes in the music: *"by means of the music I noticed somehow that it's getting slower or faster; the game itself"*–P19. For a few, the adaptivity in the game music also functioned as feedback: *"because it adapted itself the music also got faster, that showed that you're really in the flow, that you're doing well"*–P31.

Independent of their preference for or against audio in the context of exercising and sports, participants emphasized the importance of the sound effects: *"these effects, they were necessary and important [...] the effects were what I paid attention to [...] were extremely memorable"*–P15. The feedback sounds were experienced as an important and, compared to visual feedback, often prioritized performance feedback during the fitness game sessions: *"I knew, now I made a mistake [...noticed] by the tone [...] I oriented myself along this [...] I noticed the auditory more"*–P4.

The findings show a difference in audio perception: during the PT condition, the large majority of participants did not notice the music: *"I noticed I wasn't aware of the music with [the personal trainer]"–P11*, and *"with [the personal trainer] I didn't hear the music at all"*–P23. Additionally, only one participant reported that they performed faster movements during the PT condition when the speed of the music increased: "when the music got faster, I also got faster, because the rhythm spurred me on"–P31. While music was also perceived less consciously than SFX in the ExerCube, far more participants reported perceiving it and its motivating effects in the ExerCube condition than in the PT condition.

6.7 Discussion

Our design aimed to implement a holistic playful training system that is on par with PT in terms of attractiveness and effectiveness. The quantitative results and the interview and video data indicate that this was achieved through the ExerCube. There was no significant difference in flow experience nor in overall game flow score between the ExerCube conditions and the PT. Conditions were also rated similarly with regards to enjoyment and motivation. Moreover, the adaptive ExerCube was rated as more immersive than the PT condition. The interviews reflect these results; participants experienced considerable enjoyment and immersion, and were both physically and cognitively challenged, despite remaining tracking issues and the learning curve.

The results also shed light on the effects of adaptivity (Altimira et al., 2014; Marshall et al., 2016; Martin-Niedecken & Götz, 2017; Mueller et al., 2016; Rogers et al., 2018), as the ExerCube's non-adaptive counterpart served as a control condition for both adaptive ExerCube, and for the PT (wherein the adaptivity is implemented through the instructor). The quantitative results show that the nonadaptive condition was rated significantly lower with regards to optimal challenge, and higher for insufficient challenge in comparison to PT. Interestingly, the results also show that the non-adaptive ExerCube performed at a similar level as the other two conditions in terms of flow, worry, enjoyment, and motivation. This contrasts with existing literature on evaluations of related systems, wherein adaptivity facilitated these benefits (Gerling et al., 2014; Marshall et al., 2016; Martin-Niedecken & Götz, 2017; Mueller et al., 2016). We speculate that this may be a side effect of the degree of adaptivity; the system could have been set as less conservative in its audio-visual adaptivity thresholds (i.e., it slowed down too early). However, we must also point out that the non-adaptive ExerCube was otherwise the same as the adaptive version in terms of visual and auditory design, and featured the same basic physicality in its interaction concept, which increases engagement and intensifies affective experiences (Bianchi-Berthouze et al., 2007). As such, this could indicate that the system's attractiveness and effectiveness was sufficient to induce positive player experiences (Rogers et al., 2018; Sinclair et al., 2010), and that beyond that, the importance of adaptivity (i.e., higher standards of effectiveness) becomes prominent only over longer periods of use. Nevertheless, we can report that players clearly appreciated the speed-up and slow-down balancing elements, particularly in the adaptive condition, and related to both the physical and cognitive challenges (i.e., the dual flow experience).

The qualitative findings illustrated several factors in which the ExerCube differs from PT; in these factors, participants' preferences and motivations appeared the discerning variable for whether they appreciated how the ExerCube differed. The results showed a very clear difference in the perception of exertion (Holsti et al., 2013), and mental focus; this is tied closely to players' experience of the system as a game. The ExerCube was perceived as playful, challenging, and immersive, and thus distracted them from the physical exertion. This also meant that participants lacked detailed movement and posture correction (Hämäläinen et al., 2005; Reynolds et al., 2013; Turmo Vidal et al., 2018; Zaczynski & Whitehead, 2014), and some simply disliked the lack of seriousness in the context of exercise. Overall, the prototype was not conducive to claustrophobia. While some players displayed slight fear of damaging the prototype or personal injury, this was heavily outweighed by the importance and enjoyment they associated with haptic feedback (Bianchi-Berthouze et al., 2007; Mueller et al, 2014; Pasch et al., 2009).

The game scenario was perceived positively, despite minor usability issues and the strong learning curve. The results emphasize the importance of auditory and visual feedback (Turmo Vidal et al., 2018). This was reflected further by participants' strong wish for more overall feedback beyond the moment to-moment physical actions. Participants' audio perception indicates that auditory feedback signals through SFX may be more important than visual ones for a large portion of players. In terms of BGM, opinions were divided; while most thought that it was an important part of the system, this aspect was clearly less important than the SFX—a noticeable portion of participants did not consciously perceive it (Roger et al., 208). For those that did, however, it was important in facilitating motivation and immersion (Ekman, 2013; Larsson et al., 2010; Rogers et al., 2018), and for some functioned as a signal of the system's adaptivity.

6.7.1 Design Considerations

Following, we derive six generalizable design considerations, which address both attractiveness and effectiveness of a holistic fitness game setting, apply existing findings from game research to the field of exergames and extend existing knowledge with novel findings from our R&D work.

6.7.1.1 Distraction Through Holistic Design

Exertion technology and body-centered games often lack a meaningful connection between the exercises, the controller or input device, and the game design (Benford et al., 2005; Zaczynski & Whitehead, 2014). In the ExerCube, key aspects of the game design (e.g., the targets, and adaptive game challenge), helped to create a dual flow experience. In particular, it presented the players with a cognitive distraction to their physical exertion. We argue that shifting the focus of attention to game elements yields a delayed perception of exertion, which can prove useful to achieve a flow state during training.

6.7.1.2 Comprehensive Movement Feedback

In this evaluation, the PT condition was rated better than the current ExerCube iteration in terms of feedback on performance. We attribute this to the current feedback provided, an immediate right-orwrong assessment, and to the position of the overall score display, outside participants' field of view while playing. The ExerCube does not yet incorporate feedback on additional performance aspects, like feedback on and reminders about body postures, encouraging comments, and heads up about upcoming challenges, which were frequently delivered in the PT condition by the trainer, and rarely by the facilitator in the ExerCube condition. These are important instructing strategies in instructed-based training practices Turmo Vidal et al., 2018). Hence, future feedback strategies could extend binary assessments of wrong/right performance, and incorporate a wider spectrum of feedback elements, beyond error correction.

6.7.1.3 Adapt to Individual Motivations

The findings show that some participants want more "serious" workouts, and despite their enjoyment of the ExerCube, they see playful fitness systems as a warm-up option, or a leisure activity. Many others saw it as a training equivalent or substitute. The degree of movement feedback that is incorporated in the system should adapt to users' goals. This may also apply to the adaptivity thresholds; the degree of induced frustration and how quickly this turned into motivation varied, indicating a potential for customization in this aspect (Turmo Vidal et al, 2018; Zaczynski & Whitehead, 2014).

6.7.1.4 Haptic Feedback & Physical Immersion

Haptic feedback (Mueller et al., 2014) emerged as a very important aspect in the ExerCube. However, it is equally important to let players know that the system is robust and safe, i.e., it cannot break easily, and materials are soft enough to mitigate personal injury. Further, haptic feedback and its combination with physical immersion in a room appears to facilitate and enhance awareness of proprioceptive cues, as also suggested by the literature (Moran et al., 2016), which is key for physical skill acquisition (Jakubowska, 2017). Based on our findings, we speculate that while VR is unable to emulate haptic feedback and support people's proprioceptive mapping of their kinesthetic movements in the cube, the mixed reality approach is better suited to playful fitness systems.

6.7.1.5 Social Connection

One of the potential drawbacks of the ExerCube that emerged from the interview data consisted of the comparative lack of social connection. Hence, we foreground that developers of playful fitness systems should explore ways to leverage the positive aspects of the social factor that is present in the PT condition (Turmo Vidal et al., 2018). Inversely, the absence of a social connection was also a benefit for some participants. As such, while we concur with existing guidelines, we also point out that designers should be careful with the addition of social factors, and design them as opt-in to avoid the mentioned downsides: social pressure, self-consciousness, and fear of failure. Through careful design, mixed-reality playful fitness systems may be able to cover a wide middle ground between the potential isolation of VR (Spiegel, 2018), and the social factors of PT.

6.7.1.6 SFX as Main Feedback

BGM for Motivation and Immersion. SFX emerged as the prioritized feedback channel for a majority of participants, regardless of whether music generally plays a role in their everyday exercises. As such, playful fitness systems should make sure that the sound design is clear in this functionality. BGM was less consciously perceived, and so has lower priority than SFX nevertheless, almost all participants agreed the system would be missing something without it. Those aware of it emphasized its ties with motivation and immersion, and its signaling of adaptivity (Berndt & Hartmann, 2008; Ekman 2008; Ekman, 2013; Jørgensen, 2008; Larsson et al., 2010; Rogers et al., 2018). Our findings confirm that these functions of music also apply to mixed reality fitness games.

6.7.2 Future Research and Development Work

Future studies will explore the adaptivity thresholds; we speculate that the importance of high levels of effectiveness (i.e., through optimal balancing) will increase in importance over long-term use. Furthermore, we will explore a prediction/ control model for individual HR response, inspired by related work (Hoffmann et al., 2015; Ludwig et al., 2018), along with alternative physical balancing parameters, such as movement accuracy. Finally, future ExerCube iterations are being implemented to feature cooperative and competitive multiplayer scenarios (in a shared and in multiple ExerCubes). This will allow interesting avenues for future research in multiplayer balancing (e.g., effects of social facilitation (Emmerich & Masuch, 2016; Emmerich & Masuch, 2018).

6.7.3 Limitations

Since the ExerCube is still work in progress, we had to face some tracking limitations as well as some issues due to design. For example, the colors of the gates were hard to read for participants, and the upper limit of the audio-visual game speed could have been higher, as some participants felt slightly slowed down by the game. The virtual mentor led to movement timing problems, because participants assumed they were actually the mentor, rather than the avatar behind the mentor. Further, generally, the play sessions were too short; longer familiarization phases would have been an advantage. In terms of the study design, the WiFi issues reduced the sample size and thus could have led to order effects due to weakened counterbalancing (see Table 2).

6.8 Conclusion

Our work addresses the gap of physical training solutions to include both game design and fitness concepts. Towards an attractive and effective proof-of-concept system that balances both aspects, we presented the ExerCube, resulting from a holistic design approach. Further, we report on a study comparing the multi-sensory and bodily experiences of participants when playing an adaptive and non-adaptive ExerCube version, as well as a comparable PT session. Although the cube is still work-in-progress, our mixed-methods analysis revealed that the adaptive ExerCube is on par with the PT. We also found differences in participants' experience of the three main design aspects (body, controller and game scenario), particularly their perception of exertion, types and quality of movement, social factors, feedback, and audio experiences. Last, we derived considerations which inform future fitness game design and help to establish this promising body-centered game genre as an attractive and effective full-body workout setting.

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6.10 References

Altimira, D., Mueller, F., Lee, G., Clarke, J. and Billinghurst, M. (2014). Towards understanding balancing in exertion games. In Proceedings of the 11th conference on advances in computer entertainment technology. ACM, 10.

Bakeman, R. (2005). Recommended effect size statistics for repeated measures designs. Behavior Research Methods 37, 379–384.

Bateman, S., Mandryk, R., Stach, T. and Gutwin. C. (2011). Target Assistance for Subtly Balancing Competitive Play. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11). ACM, New York, NY, USA, 2355–2364.

Benford, S., Schnädelbach, H., Koleva, B., Anastasi, B., Greenhalgh, C., Rodden, T., Green, J., Ghali, A., Pridmore, T., Gaver, B., Boucher, A., Walker, B., Pennington, S., Schmidt, A., Gellersen, H., Steed (2005). Expected, Sensed, and Desired: A Framework for Designing Sensing-Based Interaction.

Berndt, A., & Hartmann, K. (2008). The functions of music in interactive media. In Joint International Conference on Interactive Digital Storytelling. Springer, 126–131.

Bianchi-Berthouze, N., Kim, W. and Patel, D. (2007). Does body movement engage you more in digital game play? And why? International conference on affective computing and intelligent interaction. Springer, 102–113.

Biddiss E. & Irwin J. (2010). Active video games to promote physical activity in children and youth: A systematic review. Archives of Pediatrics & Adolescent Medicine 164, 664–672.

Brill, P.A. (2008). Exercise your independence: functional fitness for older adults. In Journal of Aging and Physical Activity, Vol. 16. HUMAN KINETICS PUBL INC 1607 N MARKET ST, PO BOX 5076, CHAMPAIGN, IL 61820-2200 USA, S88–S89.

Calais-Germain, B. (2007). Anatomy of Movement (revised edition ed.). Eastland Press, Seattle.

Cassidy, G., & MacDonald, R. (2010). The effects of music on time perception and performance of a driving game. Scandinavian journal of psychology 51, 455–464.

Csikszentmihalyi, M. (1990). Flow: The psychology of optimal performance.

Cummings, J., & Bailenson, J. N. (2016). How immersive is enough? A meta-analysis of the effect of immersive technology on user presence. Media Psychology 19, 272–309.

Denisova, A., & Cairns, P. (2015). Adaptation in digital games: the effect of challenge adjustment on player performance and experience. In Proceedings of the 2015 Annual Symposium on Computer-Human Interaction in Play. ACM, 97–101.

Ekman, I. (2008). Psychologically motivated techniques for emotional sound in computer games. Proceedings of Audio Mostly, 20–26.

Ekman, I. (2013). On the desire to not kill your players: Rethinking sound in pervasive and mixed reality games. In FDG. 142–149.

Emmerich, K., & Masuch, M. (2016). The Influence of Virtual Agents on Player Experience and Performance. In Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play. ACM, 10–21.

Emmerich, K., & Masuch, M. (2018). Watch Me Play: Does Social Facilitation Apply to Digital Games? In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems. ACM, 100.

Engeser, S., & Rheinberg, F. (2008). Flow, performance and moderators of challenge-skill balance. Motivation and Emotion 32, 158–172.

Fery, Y.A., & Ponserre, S. (2001). Enhancing the control of force in putting by video game training. Ergonomics 44, 1025– 1037.

Gardner, R. (1989). On Performance-Enhancing Substances and the Unfair Advantage Argument. Journal of the Philosophy of Sport 16, 59–73.

Gasselseder, H.P. (2014). Dynamic music and immersion in the action-adventure an empirical investigation. In Proceedings of the 9th Audio Mostly: A Conference on Interaction with Sound. ACM, 28.

Gellish, R.L., Goslin, B.R., Olson, R.E., McDonald, A., Russi, G.D. and Moudgil, V.K. (2007). Longitudinal modeling of the relationship between age and maximal heart rate. Medicine and science in sports and exercise 39, 822–829.

Gerling, K.M., Miller, M., Mandryk, R.L., Birk, M.V. and Smeddinck, J.D. (2014). Effects of Balancing for Physical Abilities on Player Performance, Experience and Self-esteem in Exergames. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI ’14). ACM, New York, NY, USA, 2201–2210.

Icaros GmbH. 2018. Icaros. Fitness Device. (2018). Icaros GmbH, Martinsried, Germany.

Hämäläinen, P. Ilmonen, T., Höysniemi, J., Lindholm, M. and Nykänen, A. (2005). Martial arts in artificial reality. In Proceedings of the SIGCHI conference on Human factors in computing systems. ACM, 781–790.

Hamer, M., Taylor, A. and Steptoe, A. (2006). The effect of acute aerobic exercise on stress related blood pressure responses: a systematic review and meta-analysis. Biological psychology 71, 183–190.

Hardy, S., Dutz, T., Wiemeyer, J., Göbel, S. and Steinmetz, R. (2015). Framework for personalized and adaptive game-based training programs in health sport. Multimedia Tools and Applications 74, 5289–5311.

Harris, K. and Reid, D. (2005). The Influence of Virtual Reality Play on Children’s Motivation. Canadian Journal of Occupational Therapy 72, 21–29.

Hoffmann, K., Hardy, S., Wiemeyer, J. and Göbel. S. (2015). Personalized Adaptive Control of Training Load in Cardio-Exergames—A Feasibility Study. Games for health journal 4, 470–479.

Hoffmann, K., Wiemeyer, J. and Hardy, S. (2016). Prediction and control of the individual Heart Rate response in Exergames. In Proceedings of the 10th International Symposium on Computer Science in Sports (ISCSS). Springer, 171–178.

Holsti, L., Takala, T., Martikainen, A., Kajastila, R. and Hämäläinen, P. (2013). Body-controlled trampoline training games based on computer vision. In CHI'13 Extended Abstracts on Human Factors in Computing Systems. ACM, 1143–1148.

Höök, K., Ståhl, A., Jonsson, M., Mercurio, J., Karlsson, A. and Johnson, E.C.B. (2015). Somaesthetic Design. ACM Digital Library 22, 27.

Isbister, K. (2016). How Games Move Us: Emotion by Design. The MIT Press, Cambridge, MA.

Isbister, K. and Mueller, F. (2015). Guidelines for the design of movement-based games and their relevance to HCI. Human– Computer Interaction 30, 3-4, 366–399.

Jakubowska, H. (2017). Skill Transmission, Sport and Tacit Knowledge: A Sociological Perspective. Routledge. Google-Books-ID: ugoqDwAAQBAJ.

Jordan, B. and Henderson, A. (1995). Interaction Analysis: Foundations and Practice. The Journal of the Learning Sciences 4, 39–103.

Jørgensen, K. (2008). Left in the dark: playing computer games with the sound turned off. Ashgate.

Kajastila, R., &Hämäläinen, P. (2015). Motion games in real sports environments. interactions 22, 44–47.

Kajastila, R., Holsti, L. and Hämäläinen, P. (2016). The Augmented ClimbingWall: High-Exertion Proximity Interaction on aWall- Sized Interactive Surface. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16). ACM, New York, NY, USA, 758–769.

Kajastila, R., Holsti, L. and Hämäläinen, P. (2014). Empowering the Exercise: a Body-Controlled Trampoline Training Game. Int. J. Comp. Sci. Sport 13.

Karageorghis, C., & Priest, D. L. (2012). Music in the exercise domain: a review and synthesis (Part I). International review of sport and exercise psychology 5, 44–66.

Kim, S.Y.S., Prestopnik, N. and Biocca, F. A. (2014). Body in the interactive game: How interface embodiment affects physical activity and health behavior change. Computers in Human Behavior 36, 376 – 384

Kliem, A., & Wiemeyer, J. (2010). Comparison of a traditional and a video game-based balance training program. International Journal of Computer Science in Sport 9, 80–91.

Larsson, P., Väljamäe, A., Västfjäll, D., Tajadura, A., Jiménez, and Mendel Kleiner. (2010). Auditory induced presence in mixed reality environments and related technology. In The Engineering of Mixed Reality Systems. Springer, 143–163.

Loke, L., Larssen, A.T. and Robertson, T. (2005). Labanotation for Design of Movement-based Interaction. In Proceedings of the Second Australasian Conference on Interactive Entertainment (IE '05). Creativity & Cognition Studios Press, Sydney, Australia, Australia, 113–120.

Ludwig, M., Hoffmann, K., Endler, S., Asteroth, A. and Wiemeyer, J. (2018). Measurement, Prediction, and Control of Individual Heart Rate Responses to Exercise—Basics and Options for Wearable Devices. Frontiers in physiology 9.

Hyperbolic Magnetism. (2018). Beat Saber. Game [HTC Vive]. Hyperbolic Magnetism, Prague, Czech Republic.

Marquez Segura, E., Waern, A., Moen, J. and Johansson, C. (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.

Marshall, J., Benford, S., Pijnappel, S. et al. (2016). Expanding exertion gaming. International Journal of Human-Computer Studies, 1–13.

Martin-Niedecken, A. L. (2018). Designing for Bodily Interplay: Engaging with the Adaptive Social Exertion Game "Plunder Planet". In Proceedings of the 17th ACM Conference on Interaction Design and Children (IDC '18). ACM, New York, NY, USA, 19–30.

Martin-Niedecken, A. L., & Götz, U. (2016). Design and evaluation of a dynamically adaptive fitness game environment for children and young adolescents. In Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts. ACM, 205–212.

Martin-Niedecken, A. L., & Götz, U. (2017). Go with the Dual Flow: Evaluating the Psychophysiological Adaptive Fitness Game Environment "Plunder Planet". In Joint International Conference on Serious Games. Springer, 32–43.

Martin-Niedecken, A. L.; & Mekler, E. D. (2018). The ExerCube: Participatory Design of an Immersive Fitness Game Environment. In Joint International Conference on Serious Games. Springer, 263–275.

Mayring, P. (2015). Qualitative content analysis: Theoretical background and procedures. In Approaches to qualitative research in mathematics education. Springer, 365–380.

Moran, S., Jäger, N., Schnädelbach, H. and Glover, K. (2016). ExoPranayama: A Biofeedback-driven Actuated Environment for Supporting Yoga Breathing Practices. Personal Ubiquitous Comput. 20, 261–275.

Mueller, F., Gibbs, M., Vetere, F., Agamanolis, S. and Darren Edge. (2014). Designing mediated combat play. In Proceedingsof the 8th International Conference on Tangible, Embedded and Embodied Interaction. ACM, 149–156.

Mueller, F., & Isbister, K. (2014). Movement-based game guidelines. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM, 2191–2200.

Mueller, F., Khot, R. A., Gerling, K., Mandryk, R. et al. (2016). Exertion games. Foundations and Trends. in Human– Computer Interaction 10, 1–86.

Mueller, F., Vetere, F., Gibbs, M., Edge, D., Agamanolis, S., Sheridan, J. and Heer, J. (2012). Balancing Exertion Experiences. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12). ACM, New York, NY, USA, 1853–1862.

Murphy, E., Carson, L., Neal, W., Baylis, C., David Donley, and Rachel Yeater. (2009). Effects of an exercise intervention using Dance Dance Revolution on endothelial function and other risk factors in overweight children. International Journal of Pediatric Obesity 4, 205–214.

Nacke, L.E., & Grimshaw, M. (2011). Player-game interaction through affective sound. Grimshaw, Mark (ed.): Game Sound, Technology and Player Interaction.

Nes, B.M., Janszky, I., Wisløff, U., Støylen, A. and Karlsen, T. (2013). Age predicted maximal heart rate in healthy subjects: The HUNT Fitness Study. Scandinavian journal of medicine & science in sports 23, 697–704.

Nijhar, J., Bianchi-Berthouze, N. and Boguslawski, G. (2012). Does Movement Recognition Precision Affect the Player Experience in Exertion Games? In Intelligent Technologies for Interactive Entertainment, Antonio Camurri and Cristina Costa (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 73–82.

Nintendo EAD. (2006). Wii Sports. Game [Wii]. Nintendo, Kyoto, Japan.

Nintendo EAD Group No. 5. (2008). Wii Fit. Game [Wii]. Nintendo, Kyoto, Japan.

Oh, Y., & Yang S. (2010). Defining exergames & exergaming. Proceedings of Meaningful Play, 1–17.

Pasch, M., Bianchi-Berthouze, N., van Dijk, B. and Nijholt, A. (2009). Movement-based sports video games: Investigating motivation and gaming experience. Entertainment Computing 1, 2, 49 – 61.

Rare (2010). Kinect Sports. Game [Xbox 360]. (10 November 2010). Microsoft Game Studios, Redmond, WA, United States.

Reynolds, L., Sosik, V. S. and Cosley, D. (2013). When Wii Doesn't Fit: How Non-beginners React to Wii Fit's Gamification. In Proceedings of the First International Conference on Gameful Design, Research, and Applications. ACM, New York, NY, USA, 111–114.

Rheinberg, F., Vollmeyer, R. and Engeser S. (2003). Die Erfassung des Flow-Erlebens. In Diagnostik von Selbstkonzept, Lernmotivation und Selbstregulation. Hogrefe, Boston, USA, Chapter 14, 261–280.

Rogers, K., Colley, M., Lehr, D., Frommel, J., Walch, M., Nacke, L. E. and Weber, M. (2018). KickAR: Exploring Game Balancing Through Boosts and Handicaps in Augmented Reality Table Football. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems. ACM, 166.

Rogers, K., Ribeiro, G., Wehbe, R., Weber, M. and Nacke, L. E. (2018). Vanishing Importance: Studying Immersive Effects of Game Audio Perception on Player Experiences in Virtual Reality. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems. ACM, 328.

Sinclair, J., Hingston, J. and Masek, M. (2007). Considerations for the Design of Exergames. In Proceedings of the 5th International Conference on Computer Graphics and Interactive Techniques in Australia and Southeast Asia (GRAPHITE '07). ACM, New York, NY, USA, 289–295.

Sinclair, J., Hingston, P., Masek, M. and Nosaka, K. (2010). Testing an exergame for effectiveness and attractiveness. In Games Innovations Conference (ICE-GIC), International IEEE Consumer Electronics Society's. IEEE, 1–8.

Sohnsmeyer, J., Gilbrich, H. and Weisser, B. (2010). Effect of a Six-week-intervention with an Activity promoting Video Game on Isometric Muscle Strength in Elderly Subjects. Int. J. Comp. Sci. Sport 9, 2.

Soltani, P., & Salesi, M. (2013). Effects of Exergame and Music on Acute Exercise Responses to Graded Treadmill Running. GAMES FOR HEALTH: Research, Development, and Clinical Applications 2, 75–80.

Spiegel, J.S. (2018). The ethics of virtual reality technology: social hazards and public policy recommendations. Science and engineering ethics 24, 1537–1550.

Stach, T., Graham, N., Yim, J. and Rhodes, R. E. (2009). Heart Rate Control of Exercise Video Games. In Proceedings of Graphics Interface 2009 (GI '09). Canadian Information Processing Society, Toronto, Ont., Canada, Canada, 125–132.

Sweetser, P. and Wyeth, P. (2005). GameFlow: a model for evaluating player enjoyment in games. Computers in Entertainment (CIE) 3, 3 (2005), 3–3.

Tanaka, H., Monahan, K. D. and Seals, D. R. (2001). Age predicted maximal heart rate revisited. Journal of the American College of Cardiology 37, 153–156.

Technogym. 2017. Skillrow. Rowing Device and Fitness Class. (2017). Technogym, Cesena, Italy.

Turmo Vidal, L., Marquez Segura, E. and Waern, A. (2018). Movement Correction in Instructed Fitness Training: Design Recommendations and Opportunities. In Proceedings of the 2018 Designing Interactive Systems Conference (DIS '18). ACM, New York, NY, USA, 1041–1054.

Vicencio-Moreira, R., Mandryk, R.L. and Gutwin, C. (2015). Now you can compete with anyone: Balancing players of different skill levels in a first-person shooter game. In Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems. ACM, 2255–2264.

Weibel, D., & Wissmath, B. (2011). Immersion in computer games: The role of spatial presence and flow. International Journal of Computer Games Technology, 6.

Weiss, T., Kreitinger, J., Wilde, H., Wiora, C., Steege, M., Dalleck, L. and Janot, J. (2010). Effect of functional resistance training on muscular fitness outcomes in young adults. Journal of Exercise Science & Fitness 8, 113–122.

Wiemeyer, J. (2013). Music and sound in exergames. International Journal of Computer Science in Sport 12, 69–80.

Yim, J., & Graham, T.C. (2007). Using games to increase exercise motivation. In Proceedings of the 2007 conference on Future Play. ACM, 166–173.

Zaczynski, M., & Whitehead, A.D. (2014). Establishing Design Guidelines in Interactive Exercise Gaming: Preliminary Data from Two Posing Studies. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14). ACM, New York, NY, USA, 1875–1884.

7 Manuscript V: Towards Socially Immersive Fitness Games: An Exploratory Evaluation Through Embodied Sketching

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Author Contributions:
Anna Lisa Martin-Niedecken was the initiator of this work. The study design was co-developed by all authors. Elena Marquez Segura and Laia Turmo Vidal drafted the social immersive rules, which were further developed and incorporated into the existing Sphery Racer by Anna Lisa Martin-Niedecken. Anna Lisa Martin-Niedecken led the study and carried out the data collection. She was supported by Stephan Niedecken. Anna Lisa Martin-Niedecken and Katja Rogers led the analysis of the interviews while Elena Marquez Segura and Laia Turmo Vidal led the video-based interaction analysis. All authors contributed to the discussion of the results and the writing of the manuscript. All authors critically reviewed and approved the final manuscript.

7.1 Abstract

Despite many benefits of playing and exercising together in terms of motivation, engagement, and social relationships, many exergames are designed to be single player, while others implement only a facade of social play (e.g., leaderboards). The challenge remains: how can exergames be designed to balance fun, exertion, and social connection? In this work, we ran an embodied sketching activity with multiplayer variations of the Sphery Racer mixed-reality fitness game, allowing us to test physical and social game mechanics. We discuss here: i) preliminary results on how these variations support a rich training and social experience; and ii) the potential of our method to surface interesting design directions. These contributions can inspire others designing in this domain, and support the development of a rich design space for co-located exergames.

7.2 Introduction and Background

With improvements in technological progress and availability of consumer devices, exertion games have become increasingly popular, and studies (and the success of commercial applications) have shown that they provide high degrees of immersion and enjoyment (Martin-Niedecken & Götz, 2017; Martin-Niedecken et al., 2019). Benefits of social physical play are well established, indicating substantial advantages in terms of arousal (Isbister et al., 2016; Isbister et al., 2011; Lindley et al., 2008), motivation (Staiano et al., 2013; Lubans et al., 2008), engagement (Martin-Niedecken, 2018; Bianchi-Berthouze, 2013; Bianchi-Berhouze et al., 2007; Lindley et al., 2008), social connectedness (Isbister et al., 2016; Lindley et al., 2008), and adherence (Kaos et al., 2019). Joint training has similar effects (Allen, 2003; Steffens et al., 2019; Wankel & Berger, 1990). Yet most exertion games have either focused on single player experiences (Marquez Segura & Isbister, 2015), or mostly supported players acting independently Mueller et al., 2017); the design elements often support only a veneer of social play affordances (e.g., leader boards) on top of existing single player games.

The challenge of designing well-balanced social training games is not at all trivial and remains unsolved: How can one design an exertion game that is fun, an effective workout, and a rich social experience for co-located players? The challenges in this domain include physical space constraints, greater potential for injury, game balancing in terms of challenge and engagement, as well as potential negative effects of the social interaction (based on in-game events, and conferred by existing relationship dynamics).

To address this question, we engaged in an embodied sketching activity (Marquez Segura et al., 2016) together with 14 target users, to explore potential future social games using the ExerCube system (Martin-Niedecken & Mekler, 2018; Martin-Niedecken et al., 2019). Sphery Racer was used as design material and the basis for multiplayer game variations with which to test embodied core mechanics: physical (incl. cognitive and coordinative) and social game actions (Marquez Segura, 2016), game rules, and modality of play (competitive or collaborative). We present preliminary results from this exploration: emerging embodied dynamics, and which variations and game elements worked best to support the physical and social experience of players. We also reflect on the relevance of our design research method to surface interesting insights for us and other designers working in a similar domain.

7.3 The ExerCube Setting

The ExerCube by Sphery Ltd. (Martin-Niedecken & Mekler, 2018; Martin-Niedecken et al., 2019) is an immersive fitness game system that we used as a starting point in the design exploration, see Figure 1. The Sphery Racer is the first game experience built for the ExerCube system, through an iterative participatory design process. The Sphery Racer is controlled with full-body functional workout movements, scalable from moderate to high intensity. Additional cognitive challenges, conveyed to players by game mechanics and audio-visual signals, make the Sphery Racer a holistic body and brain training. To ensure a maximum attractive and effective workout experience for a wide spectrum of players, game difficulty and complexity are continuously adapted to players' individual fitness and cognitive skills during the session. Originally, the Sphery Racer was designed as a single player game.

Sphery Ltd. is now exploring how it can be further developed as a multiplayer game, by letting two co-located players use the single player version together, sharing the physical ExerCube.

Figure 1: In the ExerCube, players are surrounded by three walls that serve as projection screens and a haptic interface for energetic bodily interactions, creating a mixed-reality game setting. In the first game experience Sphery Racer – built for single player mode – the virtual game scenario takes the player on a rapid sci-fi themed underwater race. The player navigates an avatar on a hoverboard, speeding along a racing track and passing by various obstacles that provide motor-cognitive challenges. A customized motion tracking system using HTC Vive trackers (attached to players' wrists) replicates player movements with the avatar.

7.4 Multiplayer Design Elements and Variations

Building on expertise in designing embodied games (our own as well as other works), we identified several game variations featuring embodied core mechanics, game rules, and play modalities, with potential for the future social Sphery Racer game. Here, we explain main game elements at the core of these multiplayer variations as well as relevant related research. Inspired by techniques of estrangement (Wilde et al., 2017) and making the strange (Lubans et al., 2008) used in embodied design methods (Marquez Segura et al., 2016; Marquez Segura et al., 2016; Wilde et al., 2017), many variations intentionally disrupted players' ways of moving and acting within the game.

7.4.1 Bodily Orientations

We explored different bodily orientations, including playing side by side (e.g., with a controller each), but also facing one another: one player turned their back to the front screen and faced the second player, who remained able to look at the front screen (see Figure 7). The front-facing player had to guide their partner to collaboratively score – either verbally, or with gestures and movements which had to be mirrored. This disrupted classical orientations for movement-based games, i.e., facing a screen, and social play with digital games wherein players are typically placed side by side (Marquez Segura & Isbister, 2014; Marquez Segura et al., 2013).

Figure 2: Players had to dribble a ball together while playing.

Figure 3: Trackers were attached to body parts less commonly employed in exergames, including the ankle.

Figure 4: In some variations, players were tied together by a rubber band around their ankles.

Figure 5: variation, players had to stay on pieces of paper at all times, sliding around to reach targets.

Figure 6: Some players supported their co-player by lifting them up to reach the upper target with a kick.

Figure 7: To explore social affordances players face each other.

Figure 8: Some player carried the scoring player on the back

Figure 9: Paper sheets on the floor for players to either avoid, or step on them only. These constrained the play space, making players more aware of their movement.

Figure 10: One of the competitive modes – who gets the target first.

Figure 11: Competitive play – hold the other back from the target.

Figure 12: In competitive modes, some players acted as human anchor or weight to aggravate moving and scoring of their opponent player.

This open side-by-side formation (Kendon, 2010; Marquez Segura et al., 2018) does not lend itself to many social affordances (de Kort et al., 2008; Marquez Segura et al., 2018; Marquez Segura & Isbister, 2015), like monitoring intentions of the other player. While this can be seen as a negative aspect of social play (Marquez Segura & Isbister, 2015; Marquez Segura et al., 2013), the lack of certain social affordances can be used intentionally as a design resource.

7.4.2 Physical Contact

We also explored different ways of physically moving together, through "attaching" players in different ways and with different means. For example, game variations involved hitting targets while holding hands; having arms intertwined; and keeping any kind of physical contact. One cooperative and one competitive mode led to "piggyback" strategies: either one player carried around the scoring co-player on their back to the virtual target (Figure 6 and 8), or one player restricted their opponent's moving and scoring by climbing on their back (Figure 12). In some game variations, this physical connection was implemented by proxy of an object, like a ball, which had to be dribbled by both players (Figure 2), or via the use of an elastic band connecting body parts of both players, e.g., their ankles (Figure 4). Design and research show the potential of physical contact to support strong emotional reactions, help create and reinforce bonds (Gallace & Specne, 2010; Hobye, 2012), and positively impact compliance with and likeability of others (Nannberg & Hansen, 1994; Willis & Hamm, 1980). Prior research has shown that these kinds of positive effects can be leveraged in games (e.g., Dagan, et al., 2019; Huggard et al., 2013; Marshall & Tennent, 2017; Zhou et al., 2019). In game contexts, physical touch is typically better accepted than it is perceived outside of games; they provide a social "excuse" to engage in physical contact (Huggard et al., 2013).

7.4.3 Space

We also included variations that specifically proposed particular uses of the play space. For example, this included setting up a paper grid on the floor, which had to be avoided by players (Figure 9), or the opposite: they were the only places players were allowed to step on, encouraging them to slide on the pieces of paper to reach targets (see Figure 5); this could facilitate social presence (de Kort et al., 2008).

7.4.4 Movements and Body Part at Focus

We also explored if and how the game changed when different body parts and movements were at focus, e.g., instructing players to score with different body parts. We tested this for some variations, like wearing the controllers as anklets (see Figure 3). We also asked players to imagine they were wearing them elsewhere, like the head, the elbow, or the knee. We hoped this would disrupt common ways of moving, and extend players' concrete kinespheres (Marquez Segura, 2016), i.e., the immediate space around users that they use in interaction with the game system. This builds on work on alternative controllers that use game controllers worn on or strapped to body parts other than those they were designed for (e.g., (Isbister et al., 2011; Isbister et al., 2016; Zhou et al., 2019), which have potential for novel embodied experiences (Zhou et al., 2019).

7.4.5 Player Roles and Modes of Play

Inspired by recent work on the potential of asymmetrical play (Harris & Hancock, 2019; Harris et al., 2016), we explored symmetrical and asymmetrical roles of players, as well as different degrees of interdependence (Isbister et al., 2017). For example, in the variation where players were situated face-to-face, the player with their back to the front screen had to rely on they partner to score. In contrast, we had variations where both players had to hit all targets, as well as others in which they had different but comparable tasks, e.g., hitting targets that appeared at specific heights. This builds on and aligns with previous work discussing the potential of designing multiple forms of play (Mueller et al., 2017), and the use of asymmetrical play to enhance immersion, connectedness, and social engagement, in particular in immersive gameplay environments, like mixed reality games (Harris & Hancock, 2019; Zhou et al., 2019). The variations covered both collaborative and competitive modes of play.

7.5 Exploratory Evaluation: Embodied Sketching

Embodied Sketching (Marquez Segura et al., 2016) is a method to design movement-based co-located social play. It targets the design of a whole activity (Marquez Segura et al., 2013); leverages full-body engagement of designers and/or users; and considers the whole socio-physical context as design material. We used a variation of the method with end users, who experienced our game design concepts and were invited to come up with their own.

7.5.1 Participants and Procedure

We recruited seven dyads (pairs of participants) for a total of N=14 participants (5 woman, 9 men), aged 10 to 45 years (M=29.71, SD=8.27) through Sphery's social media channels and existing contacts. All pairs knew each other beforehand: three were long-time friends, two consisted of relatives (brothers, and a father with his son), one of partners and one of work colleagues. Everyone had experience working out (ten reported to work out frequently), but their gaming experience was more varied (ranging from game designers to people who never play). The majority had played the single player Sphery Racer before. Each pair engaged in gameplay for ~25 minutes in total (10 min cooperative, 3 min competitive and 10 min cooperative mode à 5 pit stops to introduce new rules and 2 breaks in between).

After a brief warm-up (co-located gameplay), pairs played between 18 and 21 game variations suggested by the facilitator, but also tried out rules suggested by participants. The Embodied Sketching activity took place during these game-play sessions. Two authors acted as facilitators by suggesting game variations, ensuring that these were deployed smoothly within the running game, helping set up the stage if needed (e.g., distributing props), and employing Wizard of Oz techniques (Bernsen et al., 1993; Dow et al., 2005) when the game variations were not technically implemented in Sphery Racer.

Finally, we conducted a semi-structured interview with each dyad (mean duration: ~30 minutes). In the interviews, we asked them about i) variations that yielded most fun or most perceived exertion, and why; ii) social aspects (e.g., interesting variations to play collaboratively/competitively, strategies the dyads used to play); and iii) which variations were both physically engaging and enjoyable.

7.5.2 Analysis

During the Embodied Sketching and the interviews, one of the study facilitators took notes and transcribed potential anchor quotes. Videos and interviews further underwent preliminary exploratory analysis. The data were analyzed informally by several authors to determine first code categories for future thematic analysis, and determine themes and further anchor quotes based on the session notes.

7.6 Results

7.6.1 Preference and Fun

All pairs expressed a preference for collaborative modes of play, because it encouraged communication and social interaction. Variations where players were physically connected were popular, either tied together with the rubber band, or with interlocked body parts (holding hands, interlaced arms). This was considered most fun by 4 pairs, and interesting from a social perspective by all. Competitive variations were preferred by two pairs, described as less structured, chaotic at times, intuitive, and fun, but also potentially risky from a physical perspective. Players highlighted novel experiential qualities of play, like sliding on paper, kicking the walls, and even falling onto the ground. Some enjoyed using props in a digital game space, and wearing controllers on different body parts.

7.6.2 Physical Contact

Four pairs mentioned collaborative variations featuring physical contact as best balancing exertion and fun, facilitating playing together "*because it was more of an intuitive motion, because you knew where the person was going*" and described as "*moving with the other*" and "*one-body movements*". Of all attachment forms, holding hands was particularly well liked. It was considered most fun by many (4 pairs), most useful to anticipate the other's movements. It made players feel like one acting at unison. Physical contact during the collaborative variations was emphasized in particular as promoting a feeling of social connectedness, most strongly while holding hands ("*it's even closer"; "unites you more than the [rubber] band*"), partly because they could better "*feel where the other one wants to go*". Physical contact was also very present for all players in competitive variations where hindering the other's movements or being the first was sought. Strategies (see Figures 10–12) ranged from obstructing the other player, to defending a particular side, occupying more space, and even physically holding their partners. Yet it was perceived with mixed opinions, even within dyads. One participant within a couple mentioned fear of hurting their partner—while this was of no concern for the latter. Some players said this fear dissipated as time passed and competition became more pronounced: "*after a few challenges [...] the focus is on how to win*". Last, three pairs (co-workers; partners; and friends) mentioned awkwardness when physically connected. They felt holding hands might be "*too intimate*", or that interlocking arms brought them "*too close*". Most dismissed awkwardness due to the context of playing a game: "*In the moment it's just necessary to fulfill the game and then, it comes natural, a natural thing to do.*"

7.6.3 Face-To-Face Formation

Game variations involving a face-to- face formation elicited interesting social communication, requiring players to pay attention to, trust, and also depend on one another. Regarding strategies, participants mentioned using verbal cues, demonstrating next movements (player facing the front screen), and mimicking the latter (player with back to the front screen). There was no consensus on what strategy was easiest; the variation received mixed reactions. While preferred by 3 pairs, one participant (playing with back towards the front screen) felt "outside the game". Participants also pointed out a high cognitive challenge for this variation.

7.6.4 Social Dynamics

Several different social dynamics became apparent in the sessions, even within a single dyad; pairs displayed leader dynamics, support, and assumptions of the other player's fitness. Players mentioned that team aspects were important during harder exercises, and they enjoyed variations that encouraged communication (e.g., "[*Switched trackers] encourages exchanges*"). For one participant, fairness was an issue in the collaborative mode ("*It felt unfair that I had to do less exercises than my co-player*!"). Fairness and the need for balanced skill levels was mentioned more often regarding competitive gameplay.

7.6.5 Perceived Exertion

Two pairs considered the competitive variations to be most physically demanding, probably due to the drive to win. Another two mentioned collaborative variations like carrying another player (2), or situations of increased speed (1). Variations involving "*extra exercise*" (e.g., "*punishment*" in one competitive variation), or carrying the partner were perceived as more physically demanding. Participants made the distinction of cognitive, physical, and social challenge; variations involving verbal coordination demanded more cognitive attention (e.g., to pass a ball between them, negotiate game space, or change behavior).

7.6.6 Balancing Exertion and Fun

Most (5 pairs) referred to collaborative variations as best balancing exertion and fun, in particular those featuring physical contact (4 pairs).

Others (2 pairs) referred to competitive variations: "Because that was the level of exhaustion that I would expect to get out doing a training like that ... and it was hilarious [both players laugh] because it was just so absurd in that small space to try and figure out how to push, block". One participant in the other pair acknowledged they lost movement accuracy. Other variations mentioned were the "Switched trackers" variation (1 pair), variations using props (1 pair), the variation wearing the controller on the feet (1 pair), and regular multiplayer use of the original Sphery Racer game without additional rules (2 pairs). Players discussed their choice would depend on who they were playing with, and their previous relationship.

7.7 Discussion and Conclusion

Here we discuss noteworthy aspects for future exploration of socially immersive fitness games.

7.7.1 Influence of Dyadic Social Constructs

Our results emphasize the need to further explore social relationship (e.g., friends, siblings, strangers) and dynamics when designing socially immersive fitness games. We observed these did not always predict how comfortable players were with physical contact, which amounted to e.g. personal preferences, cultural background, and being comfortable with sweat. Yet social dynamics pervaded the interaction, e.g., eliciting dominance cues, or feeling responsible for the partner's physical wellbeing; this also affected degree of competitiveness (e.g., protectiveness between romantic partners).

7.7.2 Mirroring vs. Verbalizing Instructions

There were differences in cognitive load between regular gameplay (instructions shown on screen), vs. when they were verbalized by players, vs. when one player showed movements to the other partner to mirror. Responses were mixed even within dyads, which needs further exploration. Yet, our results indicate that instructional modality preference is an important factor that varies from player to player within the same game, and that needs to be taken into consideration.

7.7.3 Competition vs. Collaboration

Collaboration was most preferred by players, although variations with physical contact – while highly engaging—may need some customization for those uncomfortable with it. Design affordances for player interdependence and encouraging players to anticipate the other's movements seem most effective in facilitating social connections, while care must be taken to keep both players equally part of the game. The competitive mode has substantial potential, yet it was preferred by fewer. In the future, we will focus on mitigating risk of injury, scaffolding more rules, support a degree of fair play, and game balance.

7.7.4 Embodied Sketching

This method allowed us to test the potential of game concepts and concrete design elements towards the goal of creating a fun, effective and socially enriching experience. Importantly, the games played supported our participants to reflect upon and articulate valued experiential qualities. This allowed us to better understand the potential of concrete game ideas, and how concrete game elements supported or hindered the experience of players. It also allowed us to gain a differentiated understanding of game variations across multiple contexts.

Our results represent the beginning of a potential design framework and methodology for immersive exertion games that optimally balance a fun and effective training, and a rich social experience.

7.8 References

Allen, J.B. (2003). Social motivation in youth sport. Journal of sport and exercise psychology 25, 551–567.

Bernsen, N. O., Dybkjær, H. and Dybkjær, L. (1993). Wizard of Oz prototyping: How and when. In CCI Working Papers in Cognitive Science and HCI.

Bianchi-Berthouze, N. (2013). Understanding the Role of Body Movement in Player Engagement. Human–Computer Interaction 28, 40–75.

Bianchi-Berthouze, N., Kim, W.W. and Patel, D. (2007). Does Body Movement Engage You More in Digital Game Play? and Why? In Affective Computing and Intelligent Interaction (Lecture Notes in Computer Science), Ana C. R. Paiva, Rui Prada, and Rosalind W. Editors Picard (Eds.). Springer Berlin Heidelberg, 102–113.

Dagan, E., Segura, E. M., Bertran, F. A., Flores, M. and Isbister, K. (2019). Designing “True Colors”: A Social Wearable That Affords Vulnerability. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI ’19). ACM, New York, NY, USA, 33:1–33:14.

De Kort, Y., & Ijsselsteijn, W.A. (2008). People, Places, and Play: Player Experience in a Socio-spatial Context. Computers in Entertainment 6, 18:1–18:11.

Dow, S., MacIntyre, B., Lee, J., Oezbek, C., Bolter, J.D. and Gandy, M. (2005). Wizard of Oz support throughout an iterative design process. IEEE Pervasive Computing 4, 18–26.

Gallace, A., & Spence, C. (2010). The science of interpersonal touch: an overview. Neuroscience & Biobehavioral Reviews 34, 246–259.

Harris, J., & Hancock, M. (2019). To Asymmetry and Beyond!: Improving Social Connectedness by Increasing Designed Interdependence in Cooperative Play. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI ’19). ACM, New York, NY, USA.

Harris, J., Hancock, M. and Scott, S.D. (2016). Leveraging Asymmetries in Multiplayer Games: Investigating Design Elements of Interdependent Play. In Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY ’16). ACM, New York, NY, USA, 350–361.

Hobye, M. (2012). Touchbox: intriguing touch between strangers. In CHI’12 Extended Abstracts on Human Factors in Computing Systems. ACM, New York, NY, USA, 1023–1026.

Huggard, A., De Mel, A., Garner, J. Toprak, C., Chatham, A. and Mueller, F. (2013). Musical embrace: exploring social awkwardness in digital games. In Proceedings of the 2013 ACM International Joint Conference on Pervasive and Ubiquitous Computing - UbiComp ’13. ACM Press, 725.

Isbister, K., Abe, K. and Karlesky, M. (2017). Interdependent Wearables (for Play): A Strong Concept for Design. In In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI’17). ACM Press, 465–471.

Isbister, K., Segura, E.M., Kirkpatrick, S., Chen, X., Salahuddin, S., Cao, G. and Tang, R. (2016). Yamove! A movement synchrony game that choreographs social interaction. Human Technology: An Interdisciplinary Journal on Humans in ICT Environments 12, 1 (2016), 74â˘AS¸ 102.

Isbister, K., Rao, R., Schwekendiek, U., Hayward, E. and Lidasan, J. (2011). Is More Movement Better?: A Controlled Comparison of Movement-based Games. In Proceedings of the 6th International Conference on Foundations of Digital Games (FDG '11). ACM, 331–333.

Isbister, K., Schwekendiek, U. and Frye, J. (2011)b. Wriggle: An Exploration of Emotional and Social Effects of Movement. In CHI '11 Extended Abstracts on Human Factors in Computing Systems (CHI EA '11). ACM, New York, NY, USA, 1885–1890.

Kaos, M.D., Rhodes, R.E., Hämäläinen, P. and Graham, T.C. (2019). Social Play in an Exergame: How the Need to Belong Predicts Adherence. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems. ACM, 430.

Kendon, A. (2010). Spacing and Orientation in Co-present Interaction. In Proceedings of the Second International Conference on Development of Multimodal Interfaces: Active Listening and Synchrony (COST'09). Springer-Verlag, Berlin, Heidelberg, 1–15.

Lindley, S.E., Le Couteur, J. and Berthouze, N. L. (2008). Stirring Up Experience Through Movement in Game Play: Effects on Engagement and Social Behaviour. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '08). ACM, New York, NY, USA, 511–514.

Loke, L. and Robertson, T. (2013). Moving and Making Strange: An Embodied Approach to Movement-based Interaction Design. ACM Trans. Comput.-Hum. Interact. 20, 1, 7:1–7:25.

Lubans, D.R., Foster, C. and Biddle, S JH. (2008). A review of mediators of behavior in interventions to promote physical activity among children and adolescents. Preventive medicine 47, 463–470.

Marquez Segura, E. (2016). Embodied core mechanics. Designing for movement-based co-located play. Ph.D. Dissertation. Uppsala University.

Marquez Segura, E., Fey, J., Dagan, E., Jhaveri, S. N., Pettitt, J., Flores, M. and Isbister, K. (2018). Designing Future Social Wearables with Live Action Role Play (Larp) Designers. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18). ACM, New York, NY, USA, 462:1–462:14.

Marquez Segura, E. and Isbister, K. (2015). Enabling Co-Located Physical Social Play: A Framework for Design and Evaluation. In Game User Experience Evaluation, Regina Bernhaupt (Ed.). Springer International Publishing, Cham, Switzerland, 209–238.

Marquez Segura, E., Vidal, L.A. and Rostami, A. (2016). Bodystorming for movement-based interaction design. Human Technology: An Interdisciplinary Journal on Humans in ICT Environments 12, 193–251.

Marquez Segura, E., Vidal, L. A., Rostami, A. and Waern, A. (2016). Embodied Sketching. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '16). ACM, New York, NY, USA, 6014–6027.

Marquez Segura, E., Waern, A., Moen, J. and Johansson, C. (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, New York, NY, USA, 3365–3374.

Marshall, J., &Tennent, P. (2017). Touchomatic: Interpersonal Touch Gaming In The Wild. In Proceedings of the 2017 Conference on Designing Interactive Systems (DIS '17). ACM, New York, NY, USA, 417–428.

Martin-Niedecken, A.L. (2018). Designing for Bodily Interplay: Engaging with the Adaptive Social Exertion Game “Plunder Planet”. In Proceedings of the 17th ACM Conference on Interaction Design and Children (IDC ’18). ACM, New York, NY, USA, 19–30.

Martin-Niedecken, A.L., & Götz, U. (2017). Go with the Dual Flow: Evaluating the Psychophysiological Adaptive Fitness Game Environment “Plunder Planet”. In Joint International Conference on Serious Games. Springer, 32–43.

Martin-Niedecken, A.L., &Mekler, E.D. (2018). The ExerCube: Participatory Design of an Immersive Fitness Game Environment. In Joint International Conference on Serious Games. Springer, 263–275.

Martin-Niedecken, A.L., Rogers, K., Vidal, L., Mekler, E.D. and Marquez Segura, E. (2019). ExerCube vs. Personal Trainer: Evaluating a Holistic, Immersive, and Adaptive Fitness Game Setup. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems. ACM, New York, NY, USA, 88.

Mueller, F., Gibbs, M. R., Vetere, F. and Edge, D. (2017). Designing for bodily interplay in social exertion games. ACM Transactions on Computer-Human Interaction (TOCHI) 24, 24.

Nannberg, J.C., & Hansen, C.H. (1994). Post-compliance touch: An incentive for task performance. The Journal of Social Psychology 134, 301–307.

Staiano, A.E., Abraham, A.A. and Calvert, S. L. (2013). Adolescent exergame play for weight loss and psychosocial improvement: a controlled physical activity intervention. Obesity 21, 598–601.

Steffens, N.K., Slade, E.L., Stevens, M., Haslam, S.A. and Rees, T. (2019). Putting the “we” into workout: The association of identity leadership with exercise class attendance and effort, and the mediating role of group identification and comfort. Psychology of Sport and Exercise (2019), 101544.

Wankel, L.M., & Berger, B.G. (1990). The Psychological and Social Benefits of Sport and Physical Activity. Journal of Leisure Research (1990), 167–82.

Wilde, D., Vallgårda, A. and Tomico, O. (2017). Embodied Design Ideation Methods: Analysing the Power of Estrangement. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI ’17). ACM, New York, NY, USA, 5158–5170.

Willis, F.N., & Hamm, H.K. (1980). The use of interpersonal touch in securing compliance. Journal of Nonverbal Behavior 5, 49–55.

Zhou, Z., Marquez Segura, E., Duval, J., John, M. and Isbister, K. (2019). Astaire: A Collaborative Mixed Reality Dance Game for Collocated Players. In Proceedings of the 2019 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY ’19). ACM, New York, NY, USA.

8 Manuscript VI: "HIIT" the ExerCube: Comparing the Effectiveness Of Functional High-Intensity Interval Training in Conventional vs. Exergame-Based Training

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Anna Lisa Martin-Niedecken, Alexandra Schättin and Katja Rogers drafted the manuscript and provided substantial contributions to the conception and design of the manuscript. Anna Lisa Martin-Niedecken, Alexandra Schättin and Andrea Mahrer created the study design and carefully selected the assessment methods. Anna Lisa Martin-Niedecken co-designed the ExerCube stimuli, whilst Andrea Mahrer and Alexandra Schättin co-created the conventional fHIIT protocol. Andrea Mahrer conducted the study (supervised by Anna Martin-Niedecken, Alexandra Schättin, and Eling de Bruin). Alexandra Schättin led data analysis and interpretation; Anna Lisa Martin-Niedecken and Katja Rogers also contributed to the latter. All authors critically reviewed and approved the final manuscript.

8.1 Abstract

Regular physical activity is crucial for a physically and mentally healthy lifestyle. Training methods such as high-intensity interval training (HIIT) have become increasingly popular as they enable substantial training effects in little time. HIIT typically involves recurring short phases of close-to-maximal exercise intensity, interspersed with low-intensity recovery phases. Originally mainly practiced via uniformly repetitive movements, newer variations include varied functional and holistic exercises (fHIIT). While HIIT facilitates many health advantages, fHIIT is considered more beneficial since it activates more muscles, requires more coordination, strength and balance, and mimics more natural movements which transfer well to daily life. However, fHIIT is a very intense training approach; it requires strong focus and intrinsic motivation to frequently push beyond perceived physical and mental limits. This is a common barrier to exploiting the full potential of this efficient training method. Exergames may facilitate this kind of training due to their playful, immersive, motivating nature. Yet so far, few studies have investigated HIIT-exergames – no fHIIT-exergames. This is possibly because few exergames featured both 1) an effective training concept that is comparable to HIIT, and 2) an attractive and motivating game design. We believe that this lack of holistic integration of both aspects is partly why there is currently little evidence for long-term motivation and training effects in exergame-based training. Our work addresses this gap through the design of an adaptive fHIIT protocol for the ExerCube fitness game system, creating a HIIT-level functional exergame. We conducted a within-subjects study to compare objective and subjective training intensity induced by the ExerCube against a conventional fHIIT session with healthy young adults. Furthermore, we evaluated participants' subjective experience with regards to motivation, flow, and enjoyment during both conditions. Our results contribute empirical evidence that exergames can induce HIIT-level intensity. While perceived physical exertion was slightly lower in the ExerCube condition, it yielded significantly better results for flow, enjoyment, and motivation. Moreover, the ExerCube seemed to enable a dual-domain training (higher cognitive load). We discuss these results in the context of exergame design for fHIIT, and provide practical suggestions covering topics such as safety precautions and physical-cognitive load balancing.

8.2 Introduction

Regular physical activity is crucial for a physically and mentally healthy lifestyle at all ages, as it protects against cardiovascular diseases and diabetes (Folsom et al., 2000; Steinbeck, 2001) and mental disorders such as depression (Biddle & Asare, 2011). However, especially in young adults, a lack of motivation is a common barrier to participating in regular physical activity (Teixeira et al., 2012; Trost et al., 2002). Therefore, training methods such as high-intensity interval training (HIIT) have become increasingly popular due to their good dose-effect relationship, i.e., substantial training effects in little time (MacInnis & Gibala, 2017). HIIT typically involves recurring short phases of close-to-maximal exercise intensity (beyond 80% of the maximum heart rate (HR)), interspersed with low-intensity recovery phases (Gibala et al., 2012). Originally, conventional HIIT (cHIIT) was mainly practiced via uniformly repetitive movements such as cycling on an ergometer, rowing on a rowing machine or running on a treadmill. Only 20 minutes of cHIIT three times a week can result in significant health benefits (Weston et al., 2014; Kilpatrick et al., 2014). Newer HIIT variations follow the same structure, but include functional multi-joint exercises such as squats, lunges, and burpees (Feito et al., 2018). Although cHIIT positively affects aerobic fitness, body composition, insulin sensitivity, blood lipid profile, blood pressure as well as cardiovascular functions (Babraj et al., 2009; Burgomaster et al., 2008; Kemi & Wisløff, 2010), functional HIIT (fHIIT) is considered more beneficial (Kliszczewicz et al., 2019; Menz et al., 209; Buckley et al., 2015; McRea et al., 2012). It activates more muscles (Folsom et al., 2000), requires more coordination (Wilke et al., 2019), positively affects motor functions such as strength and balance (Wilke et al., 2019; Weiss et al., 2010), and mimics more natural daily movements which transfer well to daily life (Weiss et al., 2010). Overall, HIIT has been shown to have a more beneficial impact on fitness and cardiovascular health than other exercise methods (Weston et al., 2014).

However, HIIT – in all its variations – is a very intense training approach; it requires strong focus and intrinsic motivation (Teixeira et al., 2012), as participants have to frequently reach for or push beyond their perceived physical and mental limits. It has been shown that while the high intensity component of HIIT is useful for health benefits, the motivation to continue exercising decreases as the intensity of the exercise increases (Peng & Crouse, 2011; Foster et al., 2015). Therefore, many people lose motivation when doing HIIT (Haller et al., 2019). These concerns are supported by a recent study which found that following a HIIT intervention with overweight and obese adults, only 40% adhered to the program 12 months later (Williams et al., 2018).

Exergames, if designed properly with regards to effectiveness and attractiveness (Sinclair et al., 2009), appear to be a suitable and appealing tool to facilitate this kind of training due to their playful, immersive, and motivating nature (Farrow et al. 2019; Oh & Yang, 2010). So far, only few studies have investigated exergames in the context of cHIIT (Farrow et al. 2019; Haller et al., 2019; Kessing et al., 2019; Rebsamen et al., 2019) and none in fHIIT. This is possibly because few exergames feature both 1) an effective training concept that is comparable to cHIIT, and 2) an attractive game design to sustain players' motivation (Martin-Niedecken et al., 2019). We believe that this lack of holistic integration of both aspects in exergames is partly why currently little evidence exists for long-term motivation and training effects in exergame-based training (Best, 2015). Prior to long-term investigation, the research and development community needs to design suitable exergames and investigate their feasibility. Thus, there is a need to design and evaluate exergames that combine the best of gaming and fitness; i.e., developing training tools that are both motivating and effective, while following more holistic HIIT variations.

One exergame specifically designed in terms of this holistic approach is the ExerCube: a commercial immersive fitness game setting by Sphery Ltd. (Martin-Niedecken & Mekler, 2018; Martin-Niedecken et al., 2019). The company is open to making the ExerCube available to researchers as a research platform. Thus, the first early stage functional fitness game prototype designed for this system was found to be on par with personal training regarding immersion, motivation, and flow as shown in a previous empirical study (Martin-Niedecken et al., 2019). This previous study with the ExerCube (Martin-Niedecken et al., 2019) largely employed self-reported and subjective measures, leading to a research gap with regards to its objective training intensity. An objectively high training intensity is necessary to achieve benefits of HIIT. This leads us to the following main research question: How does objective and subjective physiological training intensity in the ExerCube compare to that induced by conventional fHIIT (cfHIIT)?

Our work explores this research gap, with the goal of better understanding the design requirements of and potential for holistic HIIT in attractive and effective exergames. Therefore, we provide both design and research contributions: First, we designed a fHIIT-protocol with physiological and cognitive measures for the ExerCube system to create a HIIT-level functional exergame as well as a comparable cfHIIT protocol. We conducted a within-subjects study to compare the subjective and objective training intensity induced by a single ExerCube session and a single cfHIIT session (best practice in the fitness market) with young healthy adults. Furthermore, we evaluated participant's subjective experience including motivation, flow experience, and enjoyment during both types of training.

Our results show that the employed exergame is a feasible tool for inducing fHIIT-level training intensity. While perceived physical exertion was lower than in the cfHIIT condition, the interquartile range of the ExerCube condition's average HR reached the HIIT threshold (moderate to high-intensity). The ExerCube condition also yielded significantly better results for flow, enjoyment, and motivation. It also seemed to trigger higher cognitive load, i.e., it achieved a dual-domain training. We present a comparison with high external validity and applicability within the fitness industry; our results thus contribute empirical evidence that an exergame can be used to induce HIIT-level intensity in addition to positive effects on motivation. Based on the results, we discuss how effective and motivating exergames should be designed to implement fHIIT, and inform future explorations of their effects in terms of associated health benefits and long-term motivation.

8.3 Related Work

HIIT is an extremely time-efficient and beneficial training method, originally often performed with an ergometer, rowing machine or by running (Feito et al., 2018). Back in 1996, Tabata et al. (1996) were the first to demonstrate that a 4-minute high-intensity workout (consisting of eight 20-second bouts of all-out performance with 10-second breaks in-between) is more effective than exercising for one hour at moderate intensity. While both methods increased oxygen consumption (VO_2max), only the high-intensity training enhanced anaerobic capacity. Other studies have confirmed this finding, as also covered by a more recent systematic review (Milanović et al., 2015). Today, there are many different ways to perform HIIT. What all programs have in common is that they are characterized by periods of very heavy effort combined with periods of either complete rest or low-intensity recovery. HIIT variations such as spinning classes have been extremely popular for years; by allowing for social interaction and group dynamics, they increase or maintain motivation and help people to stay with this intensive training approach long-term (Caria et al., 2007). This is also reflected in the "Worldwide survey of fitness trends 2019" (Thompson, 2018), where HIIT took third place. Parallel to this trend, the survey reports functional fitness training in ninth place, and first place for wearable technologies such as HR sensors. This tendency clearly indicates a combination of certain training approaches (frequent endurance training with additional regular strength training and neuro-motor exercise) that most attract today's young adults, and are recommended in this combination by international guidelines on physical activity (Thompson et al., 2010; World Health Organization; 2010). However, cHIIT does not necessarily incorporate major stimuli improving strength, coordination, and motor control (Wilke et al., 2019).

8.3.1 From HIIT to HIFT to fHIIT

A newer HIIT-related variation is high intensity functional training (HIFT) which is a combination of functional multi-joint movements. These movements are adjustable to any fitness level and elicit greater muscle recruitment than more traditional exercises (Feito et al., 2018). These functional training elements, i.e., exercises that mimic movements of daily living (e.g., squats and lunges), have been shown to simultaneously improve strength and balance (Weiss et al., 2010). While HIIT exercise is characterized by relatively short bursts of repeated vigorous activity, interspersed by periods of rest or low-intensity exercise for recovery, HIFT utilizes constantly varied functional exercises and various activity durations that may or may not incorporate rest (Feito et al., 2018). The commonly practiced combination of both approaches is fHIIT.

A recent study compared effects of moderate aerobic exercise and circuit-based fHIIT on motor performance and exercise motivation in untrained adults (Wolke et al., 2019). The circuit-based fHIIT enhanced physical functions (strength and endurance) and motivation to exercise more effectively than the moderate condition. Another study examined the physiological effects of an fHIIT program on endurance and strength of physically active adults over a four-week period and found rapid physiological improvements in strength as well as in aerobic and anaerobic capacity (Kliszczewicz et al., 2019). fHIIT seems to be a beneficial variation of HIIT as its protocols allow for multiple performance and physiological adaptations that are not observed by training using unimodal HIIT methodology (Feito et al., 2018). fHIIT combines the best of HIIT and HIFT, benefits the whole body (endurance, strength, coordination, flexibility, etc.) and transfers more to daily life activities (Feito et al., 2018; Menz et al., 2019; Buckley et al., 2015; McRae et al., 2012).

Today's fitness market is reacting to this and provides special fHIIT classes with different foci (e.g., BodyAttack®) which – similar to spinning classes – enable an intense and socially motivating group workout on a holistic level. Mobile fitness apps such as Freeletics[6] further provide options for digital fHIIT-like training for users "on the go" and allow them to share, compete, and cooperate with one

[6] freeletics.com

another. Although fitness providers frame HIIT and fHIIT as motivating as possible, it remains an extremely challenging training approach.

8.3.2 Exergames: A Promising Training Tool

In today's digital age, exergames (Oh & Yang, 2010) – games that are controlled by physical exercises and provide an additional cognitive challenge for the player – are being explored as a suitable tool to introduce more people to effective training approaches and motivate them to keep on track.
Studies on exergame training in different target populations such as older adults, children, adolescents or patients indicate effects on cognitive (e.g., executive function, attention, and visual-spatial skills) (Byrne & Kim, 2019; Joronen et al., 2017; Kappen et al., 2019; Lee et al., 2017; Li et al., 2016; Stojan & Voelcker-Rehage, 2019), physical (e.g., energy expenditure, HR, and physical activity) (Byrne & Kim, 2019; Lee et al., 2017; Kaharrazi et al., 2013; Tondello et al., 2019), and mental (e.g., social interaction, self-esteem, motivation, and mood) (Lee et al., 2017; Lyons, 2015; MacRae & Robertson, 2013; Martin-Niedecken & Götz, 2017; Valenzuela et al., 2018) aspects. Generally, exergames are well known for their playful combination of physically and cognitively challenging tasks and thus provide dual-task training which promises greater effects compared to traditional single-task training approaches (Kappen et al., 2019; Benzing & Schmidt, 2018; Hardy et al., 2015; Huang et al., 2014).

Besides specific effects of exergame training, it is further known for its appealing and motivating impact, especially in physically inactive populations (Hoffmann et al., 2016; Wüest et al., 2014). By providing different players (of different motivational types (Isbister, 2016)) with audio-visually, narratively appealing, and immersive game scenarios, exergames shift players' (cognitive) focus onto the playful experience. This makes it easier to engage with a physically challenging workout (Xiong et al., 2019). Therefore, exergames have successfully been shown to increase training adherence (Kajastila & Hämäläinen, 2015), long-term motivation (Marquez Segura et al., 2013), engagement (Mueller & Isbister, 2014), immersion (Wüest et al., 2014), and flow (Sinclair et al., 2007) in players from different populations.

8.3.3 Exergame-Based HIIT

In the context of cHIIT, only few studies exist that investigated feasibility of exergames specifically designed for cHIIT with regards to physiological training outcomes or qualitative factors such as motivation and enjoyment. To the best of our knowledge, no exergames have been specifically designed and evaluated for fHIIT as of yet.

Rebsamen et al. (2019) investigated the feasibility and effects on cardiovascular fitness of an exergame-based HIIT program in untrained elderly people. The four-week training included a cognitively simple game which required fast steps for the intense training phases, and games that were cognitively more but physically less challenging for the low-intensity phases. In the low-intensity phase, participants ranged within 50–70% of their maximum heart rate (HR_{max}). Both used a step-based platform as game controller. They found that the exergame-based HIIT was a feasible and well-accepted approach and led to the intended physical intensity (70–90% of HR_{max}). Furthermore, their collected qualitative feedback identified certain aspects which could increase study outcomes in future iterations (e.g., game music, more audio-visual feedback, and increased challenge).

Farrow et al. (2019) compared different in-game conditions (allowing participants to race against their own performance or by increasing the resistance) in a head-mounted virtual reality (VR) exergame-based HIIT on an ergometer against traditional ergometer-based HIIT in physically inactive young adults. They found that VR exergaming increased enjoyment during a single bout of HIIT and led to an average of 74-89% of HR_{max} over all tested conditions in untrained individuals. Furthermore, the presence of a virtual ghost to compete with appeared to be an effective method to increase exercise intensity of VR-based HIIT.

Barathi et al. (2018) proposed and evaluated an interactive feedforward approach (a method based on competition with oneself, i.e., against an improved self-model of the player) to rapidly improve performance in a HIIT cycling VR exergame. They found that the interactive feedforward method led to improved performance (participants' average HR was above 80% of HR_{max}) while maintaining intrinsic motivation and was superior to competing against a virtual competitor.

A different VR-HIIT exergame was developed for a rowing machine by Keesing et al. (2019). They utilized gameplay mechanics and the synchronization of rowing rhythm with music rhythm to automatically induce HIIT without the need for a physical instructor. They reported that gameplay and music were both effective at inducing HIIT, but music had a stronger effect on both performance and enjoyment.

Haller et al. (2019) investigated the effects of virtual spectators (and their rhythmic clapping based on participants' ergometer speed) on motivation during a HIIT-exergame. They found that virtual crowd feedback increased cycling speed and participants' HR (to around 171 beats per minute (bpm); percentages of HR_{max} were not reported).

Finally, Moholdt et al. (2017) compared HIIT with an online multiplayer ergometer-based exergame to walking in male students. Their exergame elicited an average intensity of 73-83% of HR_{max} and a higher enjoyment than walking.

In summary, the evaluated exergames did not feature full-body functional exercises, nor necessarily a comprehensive, meaningful, audio-visually appealing, and adaptive game design. By this, we mean that – besides different training approaches – these exergames did not follow a holistic design approach covering all design levels of an exergame (Martin-Niedecken & Mekler, 2018; Martin-Niedecken et al., 2019) as well as taking into account potential interdependencies and interaction effects between these, which can affect the targeted game experience. An attractive and effective exergame design encloses the player's moving and sensing body (Mueller et al., 2011; Bianchi-Berthouze, 2007) and allows for effective and playful exercises (Marshall et al., 2016). These exercises in turn are mediated by the game controller technology which should be easily and naturally embedded into the moving player's body scheme (Shafer et al., 2014; Pasch et al., 2009; Kim et al., 2014). Moreover, the virtual game scenario represents the player's bodily input in the virtual environment and provides audio-visual as well as haptic or tactile feedback for the player and their reacting body (Shaw et al. 2017). Furthermore, the aforementioned exergames did not necessarily feature individually adjustable cognitive and physical challenges (Sinclair et al., 2009). Thus, to the best of our knowledge, while there are HIIT exergames, there are no exergames specifically designed for fHIIT, nor studies investigating them.

8.4 Materials and Method

Based on this gap, we aimed to explore whether an fHIIT exergame can induce the same training intensity as a cfHIIT in our primary research question. For this comparison, we designed an fHIIT exergame that leverages the full potential of exergames: 1) targeting whole body exercise (holistic) while also providing challenges for coordination and cognition, 2) with attractive audio-visual design to increase motivation, and 3) automatic challenge adaptation (physical and cognitive) by the system's algorithm.

The baseline for this kind of exergame was cfHIIT as it is currently practised on the fitness market, i.e., also at its full potential: 1) targeting whole body exercise, 2) with music to ensure roughly equivalent auditory appeal, and 3) with physical-challenge adaptation by the instructor, plus to a degree self-chosen adaptation. Further, cfHIIT is often offered in small groups, i.e., leveraging social factors for motivation. Given a secondary research question on whether an fHIIT exergame can compare to cfHIIT in eliciting motivation, we considered it a not field-compatible comparison if the cfHIIT would have been practised in individual sessions.

8.4.1 Stimuli: The ExerCube

The ExerCube (Martin-Niedecken & Mekler, 2018; Martin-Niedecken et al., 2019) is an immersive mixed-reality fitness game. Players are surrounded by three walls, which serve as projection screens and a haptic interface for energetic bodily interactions. A customized motion tracking system tracks players' movements via HTC Vive trackers (attached to their wrists). To ensure an ideal workout experience (in terms of attractive design and effective exercises (Sinclair et al., 2009)) for a wide spectrum of players with different skill sets, the ExerCube continuously adapts game difficulty to players' individual fitness and cognitive skills. Training intensity is measured via continuous HR tracking (i.e. players wear a HR sensor chest strap) and set to an individual pre-defined HR training range. Cognitive skills are measured via in-game performance (reacting to visual stimuli at the right time).

The Sphery Racer (see Figure 1) is a single-player game experience designed for the ExerCube setting. It was developed in several iterations based on the prototype presented and evaluated by Martin-Niedecken et al. (Martin-Niedecken & Mekler, 2018; Martin-Niedecken et al., 2019), and it is now being employed as a research object by several research groups. In collaboration with the ExerCube's development team, we modified the game design (game mechanics and audio-visual design), the level structure and the HR-based game adaption algorithm to be comparable with a cfHIIT.

Figure 1: The ExerCube training (right) reaches high-intensity training thresholds and is perceived as more motivating, enjoyable, and offering better flow than a conventional functional high-intensity interval training (left).

Like its prototypical predecessor, Sphery Racer asks players to progress along a fast-paced race track via an avatar on a hoverboard. The motion tracking system transfers player movements (based on a functional workout) onto this avatar and thus on the virtual racing track. Along the race, players are challenged by obstacles that require physical exercises (e.g., squats, lunges, and burpees) and by an additional cognitive challenge including quick information processing, which exercise has to be performed when (i.e., reaction time and coordination challenges).

The game starts with an on-boarding tutorial scene during which the game is calibrated to the exact height of the player. After successful calibration, the player's avatar drives onto the racing track and to the first instructional pitstop sequence (see Figure 2). The game contains five training pitstops (~0.5–2 min each; see Table 1), which serve as tutorials to become familiar with the respective steering movements. All exercises are instructed audio-visually (i.e., the avatar shows the exercise, written instructions are added, and a voice provides additional hints). The exercises start with low-to-moderate intensity (in terms of both physical and cognitive demand) and over time gradually increase until reaching high-intensity exercises (e.g., skippings and burpees).

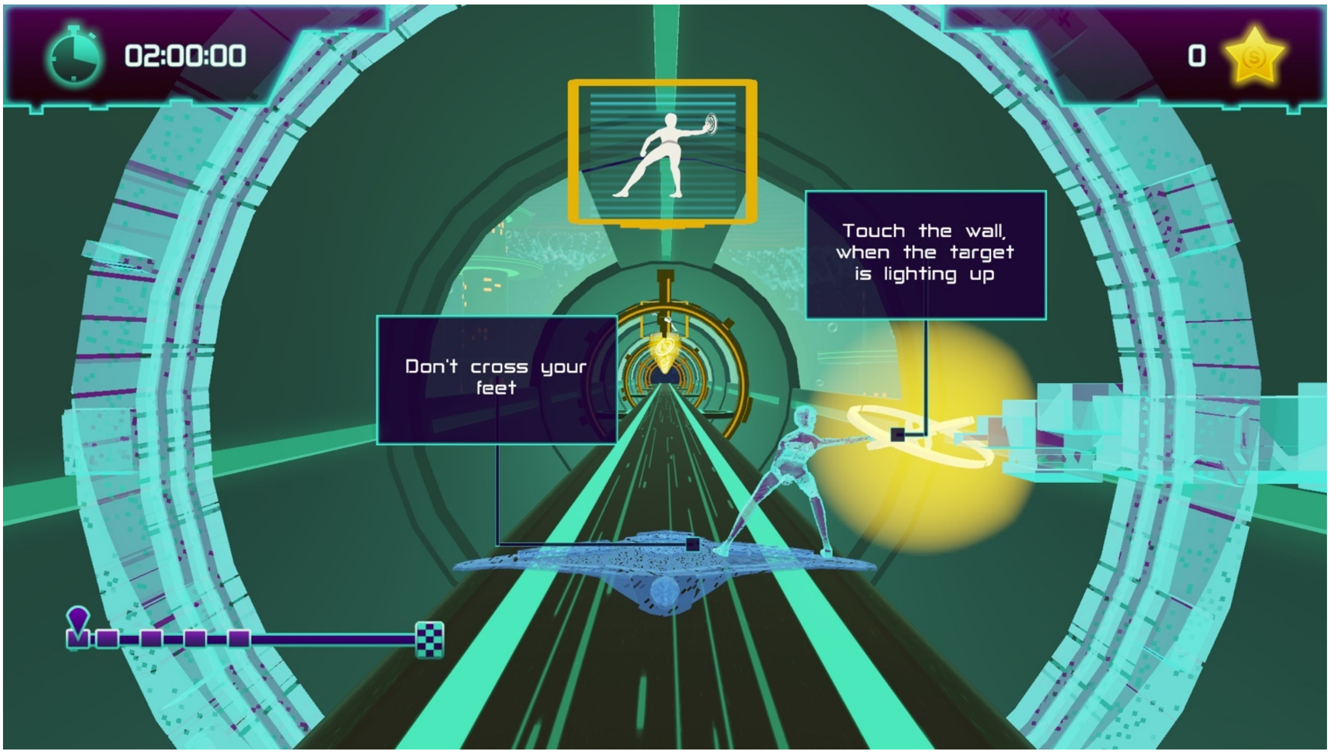

Figure 2: Pitstop Tutorial in the ExerCube.

After each pitstop, players return to the racing track, where they perform all thus-far learned movements in five racing sections. To integrate a warm-up phase followed by gradually intensifying level design, the racing section durations range from 2.5 minutes (first and second sections), to 5 minutes (third and fourth), and finally 10 minutes (last section). A complete workout session in the ExerCube takes 26-28 minutes.

The physical and cognitive game difficulty adjustments are gradually adapted independently over all training levels on a 10-point difficulty scale, where one level is defined as one step on the 10-point scale (e.g. from 5 to 6). Like previously, the algorithm determines players' individual calculated HR_{max} (CHR_{max}) based on the following formula (Nes et al., 2013):

$$CHR_{max} = 211 - 0.64 * age$$

A comprehensive fitness study proved that this formula adequately explained HR_{max} by considering an age range of 19-89 years (Nes et al., 2013). Previously, the ExerCube's algorithm also aimed towards reaching a high intensity training level (80-90% of HR_{max}), by a less finely tuned algorithm (HR <150 bpm for 0.5 min: increase speed slightly by one level; HR >175 bpm for 1 min: decrease speed slightly by one level; HR >190 bpm: decrease speed strongly by two levels). However, the algorithm was not found to reach this training intensity. For the purpose of the presented study, we refined the algorithm: During the racing sections, the game aimed to get players to a specific HR range (70-90% of CHR_{max}) and then kept them at this level. Outside of this range, a lower HR lead to an increase in physical challenge, i.e., speed, exercise frequency (one level per check), while a higher HR lead to a decrease (once 100% of CHR_{max} was reached, this decrease was sped up by three levels to ensure players' safety).

For the first two racing sections, the system employed a strategy for increasing players' HR, i.e., when 70% of CHR_{max} has not been reached, it checked actual HR_{max} every 30 seconds (whereas every 60 seconds otherwise). For the subsequent racing sections (3-5), the system checked more often (every 20 seconds in the increasing phase, and 10 seconds when above 90% of CHR_{max}).

Since the focus of the presented study was to compare the physical training intensity, we employed the same algorithm for cognitive game difficulty adjustment as used by Martin-Niedecken et al. (2019). The main cognitive challenge of the game related to how early players were visually instructed about the direction (right or left) of the upcoming exercise (e.g., a yellow gate rotates to the right for a high touch). If a player performs error-free for 20 seconds, the cognitive difficulty increased by one level (resulting in a delayed display of the direction of the next exercise) until they made three mistakes within 20 seconds, inducing a difficulty decrease by one level (resulting in an earlier display of the direction of the next exercise).

However, since the first ExerCube iteration (Martin-Niedecken et al., 2019), a new physical-cognitive challenge was added to the game scenario: players are rewarded with up to three stars depending on their timing. The audio design was developed further to emphasize the background music's rhythm, emphasize feedback via sound effects, and incorporate audio instructions. Finally, the visual feedback system was iterated for clarity.

8.4.2 Stimuli: Conventional fHIIT

To provide a comparable training protocol, we created a specific cfHIIT (see Figure 1) that was as close to actually practiced fHIIT as possible, still comparable to the ExerCube's training protocol. The ExerCube's exercises and intervals thus served as a basis to ensure a similar physical load in both conditions (Table 1).

Table 1: Exercise protocols of ExerCube and cfHIIT condition.

	ExerCube	**cfHIIT**
Duration	26-28 min	28 min
Exercises	▪ **Level 1:** Touch, Touch Low, Touch High (L/R) ▪ **Level 2:** + Squat, Jump, Punch (L/R) ▪ **Level 3:** + Lunge (L/R) ▪ **Level 4:** + Skippings ▪ **Level 5:** + Burpee	▪ **Block 1:** Warm-up ▪ **Block 2:** Suicide Drills & Jump Squat ▪ **Block 3:** High Knees to Toes & Sumo Squat with Punches ▪ **Block 4:** Mountain Climber & Lunge Jumps ▪ **Block 5:** Burpee with 180° Jump, Skippings and Skater Plyos
Intervals	▪ **Racing:** 2.5-10 min ▪ **Pit stops (breaks):** 30 sec–2 min	▪ **Workout time per block:** 4-6 min (8-12 times: 20 sec workout and 10 sec break) ▪ **Break between blocks:** 1.5–2 min
Instructor	Avatar	Coach
Difficulty & Intensity	Automatically & individually adapted	Self-regulated

cfHIIT=conventional functional high-intensity interval training.

The fHIIT protocol consists of five blocks. It started with a short warm-up block (block 1: 5 minutes stretching and toning) followed by four interval training blocks, whereby blocks 2-4 included two different exercises (e.g., jump squats and lunge jumps) and block 5 included three different exercises (e.g., skipping). This ensured an increase in physical load towards the end of the training session and matched the ExerCube's last interval. Each (non-warm-up) exercise interval consisted of 20 seconds of workout (alternately performing the respective exercises) and 10 seconds of rest. These 30 second workout-rest phases were repeated 8 times (blocks 2-4) or 12 times (block 5), leading to a total duration of 4 minutes (blocks 2-4) or 6 minutes (block 5). Interval blocks were separated by short breaks of 1.5 minutes (blocks 2-4) or 2 minutes (between blocks 4 and 5). Overall, the cfHIIT also lasted about 28 minutes.

Participants were instructed by the coach that they could individually adapt exercise intensity themselves by choosing a lower or higher level of the initial exercise (e.g., lunges instead of lung jumps) based on their subjective experience of their physical exertion. Additionally, participants were offered a mobile device positioned on the floor nearby the participants that showed their current HR in real time to allow them to keep track of their individual training intensity.

The cfHIIT session was accompanied by music that also functioned as a timer for the intervals. The selected music was specifically composed for HIIT with a pace of 128 beats per minute (bpm), while slower songs were chosen for the breaks in-between intervals to support recovery. The music was played to enhance participants' motivation, to facilitate similar conditions as the ExerCube training (accompanied by a specifically developed and adaptive sound design), and to present a realistic scenario.

8.4.3 Study Design

Two study objectives were determined to investigate the manifestation of objective and subjective components of a single fHIIT exergame session in comparison to a single cfHIIT session. The primary objective of this study was to evaluate the objective and subjective training intensity of a single fHIIT exergame session in comparison to a single cfHIIT session. The secondary objective was to assess motivation, flow, and enjoyment during the two training approaches.

The comparative study was set up as a within-subject design allowing the comparison of two different training methods: an ExerCube vs. cfHIIT session. Whereas the ExerCube session was performed as a single-player session and controlled by a certified coach, the cfHIIT was performed in small groups of 2–3 participants and instructed by the same coach. Although the ExerCube was mainly self-explanatory, the coach instructed participants and supervised them throughout the session. In the cfHIIT condition, the coach directly instructed the exercises and performed the training session together with the participants. In both sessions, the coach provided corrections, verbal support and cheers, if needed. Moreover, participants did not interact (physically or verbally) with each other in the cfHIIT session.

8.4.4 Participants

The sample size was calculated a priori based on a previous study comparing two HIIT protocols regarding cardiac responses (Schaun & Vecchio, 2018). Their study showed the following during exercise: average HR (HR_{avg}) 144.2±11.9 bpm and 130.6±10.4 bpm. Considering an 80% power and 5% significance level, a sample size of 11 subjects would have been necessary. To account for a potentially smaller difference in HR_{avg} between the two training types of our study and regarding possible losses or refusals, the final sample size was set to 16–20 participants.

Twenty participants (10 male, 10 female) were recruited by word-of-mouth and by emailing, without offering any financial compensation for the attendance. The selected study population included healthy young adults (self-reported using a health questionnaire) aged 18-35 years (M=23.8 years, SD=3.2). Fifteen participants had experience with exergames, five did not. Participants were excluded from the study if one of the following exclusion criteria was met: 1) history of cardiovascular issues or musculoskeletal injuries that would prevent training participation, (2) asthma (not controllable), (3) pain that would be reinforced by sportive activities, (4) pregnancy.

The recruited participants reported an average exercising time of M=300.3 min/week (SD=167), and reported their subjective fitness as an average of M=3.9 (SD=0.9) on a 6-point scale (1=poor, 2=satisfactory, 3=average, 4=good, 5=very good, 6=competitive). Their resting HR measured M=70.3 bpm (SD=9.9) – we thus calculated their CHR_{max} at M=195.8 (SD=2.0).

8.4.5 Measures

We distinguish between primary outcomes – relating to training intensity – and secondary outcomes, which relate to the qualitative experience of the two training types.

8.4.5.1 Primary Measures: Training Intensity.

HR data were used as an objective measurement of training intensity. The HR recording was assessed during the training session, measuring average and maximal HR (HR_{avg} and HR_{max}). To enable HR data collection, participants wore a HR receiving chest belt of the brand Wahoo (Wahoo Fitness 2014, Atlanta, Georgia, USA) – either connected to and recorded with the ExerCube (.log files) or with the compatible "Wahoo RunFit" App, which was installed on an Apple mobile device (.csv files).
The Borg 10-point rating scale was selected as a subjective measurement of training intensity (where 1=very weak and 10=very, very strong) (Borg, 1982). This scale was used to assess both physical ($Borg_{physical}$) and cognitive ($Borg_{cognitive}$) perceived exertion.

8.4.5.2 Secondary Measures: Motivation, Flow, and Enjoyment.

We employed the Situational Motivation Scale (SIMS) to assess participants' intrinsic and extrinsic motivation by 16 items (Guay et al., 2000). The SIMS questionnaire comprises four factors: intrinsic motivation, identified regulation, external regulation, and amotivation. The Flow Short Scale (FSS) was used to evaluate participants' flow experience by 13 items (Rheinberg et al., 2003). The flow experience is measured overall and as three factors: fluency of performance, absorption by activity, and perceived importance. Further, we assessed participants' enjoyment of the training via the Physical Activity Enjoyment Scale (PACES), consisting of 18 items (Kendzierski & DeCarlo, 1991; Motl et al., 2001). All three questionnaires were rated on a 7-point Likert scale (SIMS: 1=corresponds not all, 7=corresponds exactly; FSS: 1=not at all, 7=very much; PACES: (1=disagree a lot , 7=agree a lot). These standardized questionnaires were implemented as they are widely used in the area of physical exercising and exergaming and therefore allowed quantifiable comparisons.

8.4.6 Procedure

After study explanation, each participant gave written informed consent. Afterwards, participants filled out a demographic questionnaire to screen for inclusion and exclusion criteria and to assess baseline characteristics such as gender, age, physical activity time, fitness status, and exergame experience. Participants were randomly assigned to one of the two trainings. Each training session lasted 26-28 minutes. After the training, participants rated their perceived physical and cognitive exertion using the Borg Scale and answered questionnaires covering motivation, flow, and enjoyment. A training session with subsequent questionnaires was then repeated with the other type of training on a different day (but same time of day), after a minimum of four days and a maximum of fourteen days in between. The study procedure is illustrated in figure 3.

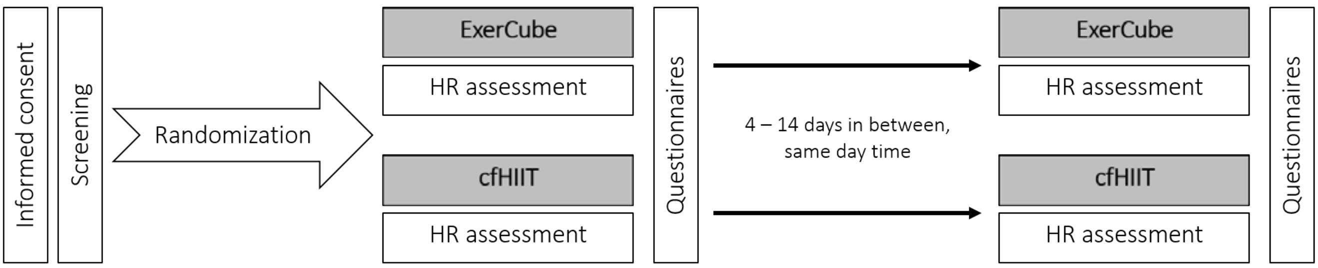

Figure 3: Study procedure for the study comparing fHIIT in an exergame to a conventional small group class.

8.4.7 Analysis

Statistical analysis was conducted in SPSS (IBM SPSS 26). The level of significance was set at $p<.05$. The comparison of the data was performed using Wilcoxon signed-rank tests. Wilcoxon signed-rank was used because the assumptions for parametric statistics were not fulfilled. Correlations were calculated using the Spearman correlation coefficient. See Cohen (Cohen, 2013) for an overview of thresholds for correlation coefficients and effect sizes.

8.5 Results

Each participant successfully completed both training sessions and all data were considered for further analysis.

8.5.1 Primary Outcomes

Table 2 presents the results from the comparison of the average and maximal measured HR and Borg values between the ExerCube and cfHIIT sessions. Absolute (z=-2.878, p=.003, r=0.46) and relative (z=-2.837 p=.005, r=0.45) average HR values were significantly higher for the cfHIIT session than for the ExerCube training. For the maximal HR, no significant differences were found for absolute (z=-0.262, p=.806, r=0.04) and relative (z=-0.302, p=.388, r=0.05) values. In terms of Borg values, the cfHIIT resulted in a significant higher physical Borg rating (z=-3.020, p=.001, r=0.48) than the ExerCube session. No significant difference was measured for the cognitive Borg (z=-1.603, p=.113, r=0.25).

Table 2: Comparison of heart rate and Borg values.

	ExerCube	cfHIIT	z	p	r
Average HR [bpm]	155.0 [141.5; 161.3]	159.5 [150.3; 167.0]	-2.878	.003*	0.46
Average HR as percentage of calculated HR_{max}	78.7 [72.6; 82.2]	81.1 [77.9; 85.8]	-2.837	.005*	0.45
Maximal HR [bpm]	182.5 [172.0; 191.0]	180.5 [176.0; 190.8]	-0.262	.806	0.04
Maximal HR as percentage of calculated HR_{max}	93.0 [88.7; 97.4]	91.6 [93.6; 101.4]	-0.302	.388	0.05
	ExerCube	**cfHIIT**	**z**	**p**	**r**
$Borg_{physical}$	7.0 [6.0;8.0]	9.0 [8.0;9.0]	-3.020	.001*	0.48
$Borg_{cognitive}$	6.5 [5.0; 8.0]	5.0 [4.0; 6.0]	-1.603	.113	0.25

*N=20. Data are shown as median [interquartile range]. Comparisons were calculated using Wilcoxon signed-rank test. *p<.05. p-values are exact values and two-tailed. Effect size r, r=0.10–0.29 indicates a small effect, r=0.30–0.49 indicates a medium effect and r≥0.50 indicates a large effect. Maximal heart rate was calculated: ($HR_{max}=211-0.64\times age$). cfHIIT=conventional functional high intensity interval training, HR=heart rate.*

8.5.2 Secondary Outcomes

The questionnaire data showed significant differences for intrinsic motivation (z=-3.566, p<.001, r=0.56), overall flow score (z=-3.663, p<.001, r=0.58), absorption by activity (z=-3.436, p=.001, r=0.54), perceived importance (z=-2.518, p=.012, r=0.40), and physical activity enjoyment (z=-3.884, p<.001, r=0.61), see table 3. For all of these factors, scores were higher for the ExerCube training session. Additionally, a significant correlation (r_s=.365, p=.021) was found between average HR and physical Borg values across all training session data (ExerCube and cfHIIT). No significant correlations were found for $Borg_{physical}$-HR_{max} (r_s=.276, p=.084), $Borg_{cognitive}$-HR_{avg} (r_s=-.224, p=.164), or $Borg_{cognitive}$-HR_{max} (r_s=-.133, p=.412).

Table 3: Comparison of questionnaires.

		ExerCube	cfHIIT	z	p	r
SIMS	intrinsic motivation	6.5 [5.8; 6.8]	5.1 [4.5; 5.5]	-3.566	<.001*	0.56
	identified regulation	6.3 [5.5; 6.7]	6.0 [5.6; 6.7]	-0.029	>.999	0.01
	external regulation	1.3 [1.0; 2.4]	1.6 [1.3; 2.7]	-0.940	.367	0.15
	amotivation	1.0 [1.0; 1.6]	1.3 [1.0; 1.9]	-0.939	.388	0.15
FSS	overall	6.0 [5.6; 6.4]	5.4 [4.9; 5.8]	-3.663	<.001*	0.58
	fluency of performance	6.3 [5.5; 6.5]	5.7 [5.2; 6.4]	-1.708	.088	0.27
	absorption by activity	6.0 [5.5; 6.5]	4.9 [4.5; 5.8]	-3.436	.001*	0.54
	perceived importance	1.7 [1.0; 2.2]	1.0 [1.0; 1.8]	-2.519	.012*	0.40
PACES		6.3 [6.0; 6.6]	5.0 [4.7; 5.5]	-3.884	<.001*	0.61

*N=20. Data are shown as median [interquartile range]. Comparisons were calculated using Wilcoxon signed-rank test. *p<.05. p-values are exact values and two-tailed. Effect size r, r=0.1–0.29 indicates a small effect, r=0.3–0.49 indicates a medium effect and r≥0.5 indicates a large effect. FSS=Flow Short Scale, cfHIIT=conventional functional high intensity interval training, SIMS=Situation Motivation Scale, PACES=Physical activity enjoyment scale.*

8.6 Discussion

Following, we discuss the meaning of our findings in the context of future design and research of effective and attractive fHIIT exergames.

8.6.1 Training Intensity: Effectiveness

The primary interest of the presented work was to objectively and subjectively investigate the intensity of an exergame-based fHIIT with the ExerCube, and thus to explore the feasibility of a specifically designed exergame as a suitable training tool for effective fHIIT. Besides this general proof of feasibility (i.e., reaching the 70-90% range of CHR_{max}), we found implications which seem to be important for future research and development work.

8.6.1.1 HR-Based Physiological Adaption

For HR_{avg}, the cfHIIT condition showed significant higher HR values compared to the ExerCube condition. This could have been caused by the ExerCube's explorative adaptation algorithm. The physical game difficulty adaptations were triggered by the system, implementing an objective orientation towards 80% of CHR_{max} (range: 70-90%) that overlaps with the high intensity zone (80-90% of CHR_{max} (Edwards, 1994)). In contrast, adaptations for cfHIIT were triggered by subjective regulations as the participants were allowed to decide on the exercise level themselves, with instruction by the coach.

For safety reasons, the ExerCube's game difficulty adaptation avoided too high HR values with regards to CHR_{max} over a longer period of time, as the exergame is meant to be used in a standalone version without supervision of a coach for the full session. However, fHIIT classes in gyms are always accompanied by a certified coach, and can thus aim for a more persistent high HR_{avg}.

It should also be noted that the CHR_{max} for the ExerCube's physical-difficulty adaption was determined via calculation based on a well validated generalizable formula (Nes et al., 2013). However, actual HR_{max} can differ; it is a very individual parameter depending on a variety of aspects in addition to age (e.g., gender, fitness level (Nes et al., 2013), and genetics (Wang et al., 2009)). This could be a reason why the ExerCube's provided training levels did not fully meet respective individual capacity, and thus its HR_{avg} remained slightly below 80% of HR_{max}. Yet the relative HR_{avg} values (% of CHR_{max}) of the ExerCube training did reach values in the fHIIT zone (80-90% of HR_{max} (Edwards, 1994)) for parts of the game duration – and is well situated in the moderate-intensity zone (70-80% of HR_{max} (Edwards, 1994)).

Furthermore, while the design for safety has to be considered, the measured HR_{max} values show that the ExerCube has the capacity to reach high exercise intensities and to trigger high HR values in young healthy adults.

Future fHIIT exergames should therefore allow for a more individual game difficulty adaption by allowing users to manually insert their pre-assessed individual CHR_{max} or more specific HR prediction models (Ludwig et al., 2018), to then serve as the basis for the algorithm (Hoffmann et al., 2016). In the interest of safety, the implemented explorative algorithm used in the present study could also be refined further to check HR – and if required – adapt more frequently (e.g., every 10-20 seconds from the very beginning of the game).

8.6.1.2 Adaptive Training Protocols

Another reason for the significant difference in HR_{avg} could have been the small deviations of the training protocols of both study conditions (i.e., different intervals and sequences in the training structure of the cfHIIT). However, we aimed at designing a realistic cfHIIT that is comparable to those in fact practiced in the current fitness sector.

It would be interesting to explore different variations of fHIIT protocols in an exergame and link the game difficulty adjustment more closely to the exercises provided in the respective game level. For example, instead of slowing down the game speed when measured HR is too high, provide less exhausting exercises (e.g., holding tasks) and a higher cognitive load.

8.6.1.3 Effects of Physical-Cognitive Challenge

Another aspect of note is the ExerCube's higher multi-sensory stimulation compared to the cfHIIT, which could have also influenced the HR_{avg}. While the cfHIIT was a single-task training, which required functional movements of participants' own body only, the dual-task training in the ExerCube required participants to concurrently process and react to multi-sensory stimuli (audio-visual, spatial, and game mechanical) while still performing a fHIIT to control the game. This approach constituted more comprehensive executive and attentional functions ((pre-)frontal lobe functions (Funahashi & Andreau. 2013)) than the cfHIIT, and this in turn likely activated more cognitive resources. This was also reflected in the results for perceived exertion of the cognitive domain during our study revealing higher values for the ExerCube compared to the cfHIIT. A subsequent side effect on physical performance can be explained with findings from motor-cognitive research: individuals tend to slow down physical movement when asked to perform a relatively challenging secondary dual-task simultaneously (Yogev-Seligmann et al., 2010). Interestingly, we also found that (while not a significant correlation) participants showed higher HR values for lower cognitive exertion values; in contrast, lower HR values were assessed for higher cognitive load values. This tendency could be caused by the destabilizing effect of dual-tasks that involve competing demands for cognitive and physical resources; this effect is termed "dual-task cost", wherein motor-cognitive interferences can cause deterioration of one or both tasks (Al-Yahya et al., 2011). Thus, we speculate that the multi-sensory stimulation in the ExerCube condition required additional cognitive resources, which in turn limited the resources for physical performance and, therefore, the possibility to reach higher training intensity while also providing additional cognitive training benefits (Stojan & Voelcker-Rehage, 2019; Benzing et al., 2016; Herold et al., 2018).

Future exergame research should further explore and keep in mind these interdependencies. For instance, the ExerCube or a similar exergame could be adapted to investigate effects of varying cognitive loads with a constant physical load on training intensity. Future exergame design should extend existing approaches of physical-cognitive game difficulty adaptation and develop environments that allow for more individualized cognitive-physical and physical-cognitive game challenges. This will allow exergame designers to provide a more individualized dual-domain training (Kappen et al., 2019; Stojan & Voelcker-Rehage, 2019; Benzing & Schmidt, 2018; Hardy et al., 2015; Huang et al., 2014), which could then focus more strongly on either cognitive or on physical challenges depending on the player's needs and skills.

8.6.2 Training Experience: Attractiveness

Additionally of interest to our work was the comparison of the subjective training experience of exergame-based fHIIT with the ExerCube to a cfHIIT. Besides the general proof of feasibility of the ExerCube to be an attractive fHIIT exergame, we again found implications for future research and design towards more appealing exergames.

8.6.2.1 Shifting Attentional Focus

Regarding training motivation, enjoyment, and flow experience, our study showed significantly higher values in favor of the ExerCube condition. This might have various reasons. In the ExerCube condition, participants' focus seemed to be primarily tied to the game environment and not to their bodily exertion (which indeed was less than in the cfHIIT condition). One indication for this attentional focus shift is the previously discussed higher rated cognitive challenge for the ExerCube condition. Furthermore, flow was significantly higher rated for the ExerCube condition (assessed by FSS) and especially the items "absorption by activity" and "perceived importance". These results match findings of the ExerCube study by Martin-Niedecken et al. (2019), wherein participants reported that they were totally immersed by the game and had to focus on its mechanics to succeed (i.e., a flow experience). In contrast, participants were much more focused on their body with the study's personal coach condition, as they had to concentrate to keep up and perform the exercises correctly. This included more social pressure, i.e., wanting to perform well in front of the coach. These results in combination with those in this study point towards a trade-off between the two training options. Exergames can provide a degree of playfulness and strong cognitive focus that frees players of the perceived physical and additional social challenges elicited by the presence of coaches. However, coaches provide a degree of guidance and "workout spirit" that leads to greater accuracy in terms of movement; effects that exergames should strive for in their design.

Future exergame design and research should explore in between variations of exergames and trainers to combine the benefits of both approaches (Turmo Vidal et al., 2018).

8.6.2.2 User-Centered Design

In the exergame condition, game difficulty and complexity were automatically balanced based on each participant's fitness and gaming skills. Thus, in theory, they were never physically over- or under-challenged, nor stressed or bored. Being in this "dual flow" zone is generally considered an optimal workout mode in terms of motivation, enjoyment, and performance (Sinclair et al., 2009; Martin-Niedecken et al., 2019; Martin-Niedecken & Götz, 2017; Jackson & Csikszentmihalyi, 1999). These optimal user-centered demands were reflected by the significant higher rated PACES and the item "intrinsic motivation" (SIMS) for the ExerCube condition, and were likely due to the multi-sensory implementation that was developed and refined by a collaboration of game designers, sport scientists, and the target population in iterations and studies. Co-design allows for including wishes and needs specific to a target group and has been shown to positively affect people's identification with and enjoyment of a product (Martin-Niedecken et al., 2019; Martin-Niedecken & Götz, 2017; Birk et al., 2016). Enjoyment of an activity has a positive impact on physical activity participation and adherence and therefore plays an important role in maintaining an activity-based health care intervention in the long term (Hagberg et al., 2019; Rhodes et al., 2009; Salmon et al., 2003). The results here substantiate the potential of enjoyable exergames for the promotion of physical activity through careful and iterative design and might therefore be a particularly suitable tool for individuals who have trouble motivating themselves to undertake conventional training methods (Hoffmann et al., 2016; Wüest et al., 2014; Moholdt et al., 2017).

Future exergame developments should, therefore, focus on more target population-centric co-designs (i.e., including potential players, but also trainers or therapists in the design process) to ensure that the result meets the players' expectations as well as specific needs and requirements.

8.6.2.3 Social Exergaming Effects

One difference between our two training stimuli was the single-player mode in the ExerCube session as opposed to the cfHIIT being conducted in a group of 3-4 people, as is common on today's fitness market. We had assumed that this would be a point in favour of the cfHIIT, as social experiences can increase motivation and enjoyment (Mueller et al., 2011; Campbell et al., 2008; Mandryk et al., 2014). However, the questionnaires showed no significant values in favor of cfHIIT. With regards to motivation, flow experience, and enjoyment of physical activity the ExerCube yielded significantly higher results.

Based on this, it could be assumed that the social factors involved in cfHIIT are not as influential as we had expected. However, we know from related work that in games and exergames the presence of a physical (Emmerich & Masuch, 2018) or virtual (Farrow et al., 2019; Emmerich & Masuch, 2018) co-player or component often enhances player motivation as long as players feel a need to belong (Kaos et al., 2018). This could have increased the experiential quality in the ExerCube. It should also be noted that the social group experience in the cfHIIT also has potential downsides; the social pressure to perform well in front of the coach and other class attendees – similarly observed by Martin-Niedecken et al. (2019) with the personal coach condition – can be overwhelming. Social facilitation is, thus, generally considered positive in exergames, but can instead negatively affect game experiences depending on individual characteristics (e.g., how comfortable is the player at being observed and urged on while working out).

Social facilitation effects in fHIIT exergames are an important aspect for future research. It is in theory possible to play the original Sphery Racer game with the ExerCube in co-located cooperative or competitive mode. This will have to be explored in future work.

8.6.3 Limitations

One limitation of the study consists of the differences between our two training stimuli. While we endeavoured to design the two conditions to be as comparable as possible, we also wanted to keep the cfHIIT version as realistic as possible. Thus, the racing sections of the ExerCube are equivalent for the intervals of the cfHIIT and the lower-intensity pitstops are the equivalent for the resting phases of the cfHIIT. However, there are differences in movement sequence (e.g., repetitive movements per block in the cfHIIT versus varied movements in the ExerCube) and compositions (e.g., different exercises per block in the cfHIIT versus accumulated exercises over time in the ExerCube). This should be considered in future work with the ExerCube.

This also includes not artificially removing potentially beneficial social factors from the cfHIIT condition by exploring this in individual sessions instead of groups. However, as the player experience factors were largely higher for the ExerCube condition, a lack of social factors in exergames may not be as much of an issue as expected. However, it should also be noted that participants experienced the ExerCube for the first time in this study, whereas as some of them had prior experience with cfHIIT group classes. The questionnaire results could thus have been influenced by a novelty effect. Future work has to explore whether this effect remains long-term when players become used to the ExerCube, or when the cfHIIT condition is conducted with pre-existing social groups with prior social bonds (our participants did not know each other or exercise together prior to the study).

Another difference lay in the audio-visual scenarios of the stimuli. The ExerCube provides music that adapts to in-game events, with the addition of sound effects for feedback (shown to be important for exergames in previous work (Martin-Niedecken et al., 2019)). Our cfHIIT stimuli did have comparable music, however, it was not adaptive beyond following and matching the exercise and rest periods. There are some indications that adaptive music can benefit game experiences (Rogers & Weber, 2019; Wharton and Collins, 2011) – and music certainly positively influences exercise (Karageorghis & Priest, 2012) – nevertheless, this has largely not been explored in the exergame context.

When compared to the exergame condition, another difference is that the cfHIIT featured a degree of subjective self-regulation (participants deciding which exercise version they picked, and how fast and intensely to perform them – albeit with guidance from the coach), while the ExerCube featured more objective adjustments (automatically based on the algorithm). We emphasize that we did offer all participants a mobile device positioned on the floor nearby which showed their current HR in real time. As such, they (including the coach) were in theory able to keep track of their individual training, although we cannot report to what degree they used this option.

Finally, the maximal CHR_{max} in the ExerCube was calculated by a formula that determines relative HR values; these kinds of formulas are based on data from the general population. However, this study was conducted with young healthy adults, whose individual HR_{max} could potentially be higher than what is predicted by the formula. In future work, we will explore whether the determination of individual HR_{max} can provide a more customized, higher training intensity without neglecting safety concerns.

8.7 Conclusion

The aim of this study was to investigate whether an exergame specifically designed for fHIIT can reach a training intensity comparable with cfHIIT classes and the levels of physical load required for physiological HIIT benefits. Regarding the exergame's training intensity, i.e., its effectiveness, our results reveal that the ExerCube reached high range of physiological training intensity, although the specific adaptation algorithm may need to be adjusted to reach it on average throughout the session. While the cfHIIT yielded higher training intensity than the ExerCube, participants experienced significantly higher flow, training enjoyment, and motivation in the ExerCube, as well as less perceived physical exertion. Therefore, our results indicate that specifically designed exergames such as the ExerCube are a motivating and enjoyable training approach with the capacity to reach high training intensities. We concluded that exergames or fitness games – if designed properly with regards to fitness protocol (effectiveness) and game design (attractiveness) – have the potential to increase physical activity and training effects to HIIT levels and therefore may be able to facilitate health benefits in young adults. Our results can inform future R&D work which is needed to examine further important aspects in exergames, such as (1) individual and sport-specific determination of physical and cognitive parameters used for pre-game settings and in-game adaptations, (2) refined balancing of cognitive and physical load, and (3) long term effects and training adherence.

8.8 Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be interpreted as a potential conflict of interest. AMN is the Co-Founder and CEO of the startup company Sphery Ltd that developed the ExerCube. AS has been working at Sphery since November 2019, but was not yet employed at the time of the study conduction. No revenue was paid (or promised to be paid) directly to AMN, to Sphery or the research institutions.

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8.10 References

Al-Yahya, E., Dawes, H., Smith, L., Dennis, A., Howells, K. and Cockburn, J. (2011). Cognitive motor interference while walking: a systematic review and meta-analysis. Neuroscience & Biobehavioral Reviews 35, 715-728.

Babraj, J.A., Vollaard, N.B., Keast, C., Guppy, F.M., Cottrell, G. and Timmons, J.A. (2009). Extremely short duration high intensity interval training substantially improves insulin action in young healthy males. BMC endocrine disorders 9, 3.

Barathi, S.C., Finnegan, D.J., Farrow, M., Whaley, A., Heath, P., Buckley, J., Dowrick, D.J., Wuensche, B.C., Bilzon, J.L. and O'Neill, E. (2018). Interactive feedforward for improving performance and maintaining intrinsic motivation in VR exergaming, Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, pp. 1-14.

Benzing, V. and Schmidt, M. (2018). Exergaming for children and adolescents: strengths, weaknesses, opportunities and threats. Journal of clinical medicine 7, 422.

Benzing, V., Heinks, T., Eggenberger, N. and Schmidt, M. (2016). Acute cognitively engaging exergame-based physical activity enhances executive functions in adolescents. PloS one 11.

Best, J. R. (2015). Exergaming in youth. Zeitschrift für Psychologie.

Bianchi-Berthouze, N., Kim, W.W. and Patel, D. (2007): Does body movement engage you more in digital game play? and why? International conference on affective computing and intelligent interaction, Springer, pp. 102-113.

Biddle, S. J. and Asare, M. (2011). Physical activity and mental health in children and adolescents: a review of reviews. British journal of sports medicine 45, 886-895.

Birk, M.V., Atkins, C., Bowey, J.T. and Mandryk, R.L. (2016). Fostering intrinsic motivation through avatar identification in digital games, Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, pp. 2982-2995.

Borg, G.A. (1982). Psychophysical bases of perceived exertion. Medicine & Science in Sports & Exercise.

Buckley, S., Knapp, K., Lackie, A., Lewry, C., Horvey, K., Benko, C., Trinh, J. and Butcher, S. (2015). Multimodal high-intensity interval training increases muscle function and metabolic performance in females. Applied Physiology, Nutrition, and Metabolism 40, 1157-1162.

Burgomaster, K.A., Howarth, K.R., Phillips, S.M., Rakobowchuk, M., MacDonald, M.J., McGee, S.L. and Gibala, M.J. (2008). Similar metabolic adaptations during exercise after low volume sprint interval and traditional endurance training in humans. The Journal of physiology 586, 151-160.

Byrne, A.M., & Kim, M. (2019). The Exergame as a Tool for Mental Health Treatment. Journal of Creativity in Mental Health 14, 465-477.

Caria, M.A., Tangianu, F., Concu, A., Crisafulli, A. and Mameli, O. (2007). Quantification of Spinning® bike performance during a standard 50-minute class. Journal of sports sciences 25, 421-429.

Cohen, J. (2013). Statistical power analysis for the behavioral sciences, Routledge.

Edwards, S. (1994). The heart rate monitor book, LWW.

Emmerich, K., & Masuch, M. (2018). Watch Me Play: Does Social Facilitation Apply to Digital Games? Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, pp. 1-12.

Farrow, M., Lutteroth, C., Rouse, P.C. and Bilzon, J.L. (2019). Virtual-reality exergaming improves performance during high-intensity interval training. European journal of sport science 19, 719-727.

Feito, Y., Heinrich, K.M., Butcher, S.J. and Poston, W.S.C. (2018). High-intensity functional training (HIFT): Definition and research implications for improved fitness. Sports 6, 76.

Folsom, A. R., Kushi, L. H., & Hong, C. P. (2000). Physical activity and incident diabetes mellitus in postmenopausal women. *American Journal of Public Health*, *90*(1), 134.

Foster, C., Farland, C.V., Guidotti, F., Harbin, M., Roberts, B., Schuette, J., Tuuri, A., Doberstein, S.T. and Porcari, J.P. (2015). The effects of high intensity interval training vs steady state training on aerobic and anaerobic capacity. Journal of sports science & medicine 14, 747.

Funahashi, S., & Andreau, J.M. (2013) .Prefrontal cortex and neural mechanisms of executive function. Journal of Physiology-Paris 107, 471-482.

Gibala, M. J., Little, J. P., MacDonald, M. J., & Hawley, J. A. (2012). Physiological adaptations to low-volume, high-intensity interval training in health and disease. *The Journal of physiology*, *590*(5), 1077-1084.

Guay, F., Vallerand, R.J. and Blanchard, C. (2000). On the assessment of situational intrinsic and extrinsic motivation: The Situational Motivation Scale (SIMS). Motivation and emotion 24, 175-213.

Hagberg, L. Lindahl, B., Nyberg, L. and Hellénius, M.L. (2009). Importance of enjoyment when promoting physical exercise. Scandinavian journal of medicine & science in sports 19, 740-747.

Haller, J.C., Jang, Y.H., Haller, J., Shaw, L. and Wünsche, B.C. (2019). HIIT The Road: Using Virtual Spectator Feedback in HIIT-based Exergaming, Proceedings of the Australasian Computer Science Week Multiconference, pp. 1-9.

Hardy, S., Dutz, T., Wiemeyer, J., Göbel, S. and Steinmetz, R. (2015). Framework for personalized and adaptive game-based training programs in health sport. Multimedia Tools and Applications 74, 5289-5311.

Herold, F., Hamacher, D., Schega, L. and Müller, N.G. (2018). Thinking while moving or moving while thinking–concepts of motor-cognitive training for cognitive performance enhancement. Frontiers in aging neuroscience 10, 228.

Hoffmann, K., Wiemeyer, J. and Hardy, S. (2016). Prediction and control of the individual Heart Rate response in Exergames, Proceedings of the 10th International Symposium on Computer Science in Sports (ISCSS), Springer, pp. 171-178.

Huang, T., Larsen, K., Ried-Larsen, M., Møller, N. and Andersen, L.B. (2014). The effects of physical activity and exercise on brain-derived neurotrophic factor in healthy humans: A review. Scandinavian journal of medicine & science in sports 24, 1-10.

Isbister, K. (2016). How games move us: Emotion by design, Mit Press.

Jackson, S.A., & Csikszentmihalyi, M. (1999). Flow in sports, Human Kinetics.

Joronen, K., Aikasalo, A. and Suvitie, A. (2017). Nonphysical effects of exergames on child and adolescent well-being: a comprehensive systematic review. Scandinavian journal of caring sciences 31, 449-461.

Kajastila, R., & Hämäläinen, P. (2015). Motion games in real sports environments. interactions 22, 44-47.

Kaos, M.D., Rhodes, R.E., Hämäläinen, P. and Graham, T.N. (2019). Social play in an exergame: how the need to belong predicts adherence, Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, pp. 1-13.

Kappen, D.L., Mirza-Babaei, P. and Nacke, L.E. (2019). Older adults' physical activity and exergames: a systematic review. International Journal of Human–Computer Interaction 35, 140-167.

Karageorghis, C.I., & Priest, D.-L. (2012). Music in the exercise domain: a review and synthesis (Part I). International review of sport and exercise psychology 5, 44-66.

Keesing, A., Ooi, M., Wu, O., Ye, X., Shaw, L. and Wünsche, B.C. (2019). Hiit with hits: Using music and gameplay to induce hiit in exergames, Proceedings of the Australasian Computer Science Week Multiconference, pp. 1-10.

Kemi, O. J., & Wisløff, U. (2010). High-intensity aerobic exercise training improves the heart in health and disease. Journal of cardiopulmonary rehabilitation and prevention 30, 2-11.

Kendzierski, D., & DeCarlo, K.J. (1991). Physical activity enjoyment scale: Two validation studies. Journal of sport & exercise psychology 13.

Kilpatrick, M.W., Jung, M.E. and Little, J.P. (2014). High-intensity interval training: A review of physiological and psychological responses. ACSM's Health & Fitness Journal 18, 11-16.

Kim, S.Y.S., Prestopnik, N. and Biocca, F.A. (2014). Body in the interactive game: How interface embodiment affects physical activity and health behavior change. Computers in Human Behavior 36, 376-384.

Kliszczewicz, B., McKenzie, M. and Nickerson, B. (2019): Physiological adaptation following four-weeks of high-intensity functional training. Vojnosanitetski pregled 76, 272-277.

Lee, S., Kim, W., Park, T. and Peng, W. (2017): The psychological effects of playing exergames: A systematic review. Cyberpsychology, Behavior, and Social Networking 20, 513-532.

Li, J., Theng, Y.-L., & Foo, S. (2016). Effect of exergames on depression: a systematic review and meta-analysis. Cyberpsychology, Behavior, and Social Networking 19, 34-42.

Lu, A.S., Kharrazi, H., Gharghabi, F. and Thompson, D. (2013). A systematic review of health videogames on childhood obesity prevention and intervention. GAMES FOR HEALTH: Research, Development, and Clinical Applications 2, 131-141.

Ludwig, M., Hoffmann, K., Endler, S., Asteroth, A. and Wiemeyer, J. (2018). Measurement, prediction, and control of individual heart rate responses to exercise—Basics and options for wearable devices. Frontiers in physiology 9 (2018) 778.

Lyons, E.J. (2015). Cultivating engagement and enjoyment in exergames using feedback, challenge, and rewards. Games for health journal 4, 12-18.

MacInnis, M.J., & Gibala, M.J. (2017). Physiological adaptations to interval training and the role of exercise intensity. The Journal of physiology 595, 915-2930.

MacRay, A., & Robertson, J. (2013). Understanding exergame users' physical activity, motivation and behavior over time, Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 1251-1260.

Mandryk, R.L., Gerling, K.M. and Stanley, K.G. (2014). Designing games to discourage sedentary behaviour, Playful User Interfaces, Springer, pp. 253-274.

Marquez Segura, E., Waern, A., Moen, J. and Johansson, C. (2013). The design space of body games: technological, physical, and social design, Proceedings of the SIGCHI conference on Human Factors in computing systems, pp. 3365-3374.

Marshall, J., Benford, S. and Pijnappel, S. (2016). Expanding exertion gaming. International Journal of Human-Computer Studies 90, 1-13.

Martin-Niedecken, A. L., Rogers, K., Vidal, L. A., Mekler, E. D. and Marquez Segura, E. (2019). ExerCube vs. Personal Trainer: Evaluating a Holistic, Immersive, and Adaptive Fitness Game Setup. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems. ACM, New York, NY, USA, 88, pp. 1-15.

Martin-Niedecken, A.L., & Mekler, E.D. (2018). The ExerCube: Participatory Design of an Immersive Fitness Game Environment, Joint International Conference on Serious Games, Springer, pp. 263-275.

Martin-Niedecken, A.L., & Götz, U. (2017). Go with the dual flow: Evaluating the psychophysiological adaptive fitness game environment “Plunder Planet”, Joint International Conference on serious games, Springer, pp. 32-43.

McRae, G., Payne, A., Zelt, J.G., Scribbans, T.D., Jung, M.E., Little, J.P. and Gurd, B.J. (2012). Extremely low volume, whole-body aerobic–resistance training improves aerobic fitness and muscular endurance in females. Applied Physiology, Nutrition, and Metabolism 37, 1124-1131.

Menz, V., Marterer, N., Amin, S.B., Faulhaber, M., Hansen, A.B. and Lawley, J.S. (2019). Functional Vs. Running Low-Volume High-Intensity Interval Training: Effects on VO2max and Muscular Endurance. Journal of sports science & medicine 18, 497.

Milanović, Z., Sporiš, G. and Weston, M. (2015). Effectiveness of high-intensity interval training (HIT) and continuous endurance training for VO 2max improvements: a systematic review and meta-analysis of controlled trials. Sports medicine 45, 1469-1481.

Moholdt, T., Weie, S., Chorianopoulos, K., Wang, A.I. and Hagen, K. (2017). Exergaming can be an innovative way of enjoyable high-intensity interval training. BMJ open sport & exercise medicine 3 (2017) e000258.

Motl, R.W., Dishman, R.K., Saunders, R., Dowda, M., Felton, G. and Pate, R.R. (2001). Measuring enjoyment of physical activity in adolescent girls. American journal of preventive medicine 21, 110-117.

Mueller, F., Edge, D., Vetere, F., Gibbs, M.R., Agamanolis, S., Bongers, B. and Sheridan, J.G. (2011). Designing sports: a framework for exertion games, Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 2651-2660.

Mueller, F., & Isbister, K. (2014). Movement-based game guidelines, Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 2191-2200.

Nes, B., Janszky, I., Wisløff, U., Støylen, A. and Karlsen, T. (2013). Age-predicted maximal heart rate in healthy subjects: The HUNT F itness S tudy. Scandinavian journal of medicine & science in sports 23, 697-704.

Oh, Y., &Yang, S. (2010). Defining exergames & exergaming. Proceedings of Meaningful Play, 1-17.

Pasch, M., Bianchi-Berthouze, N., Dijk, B. van and Nijholt, A. (2009). Movement-based sports video games: Investigating motivation and gaming experience. Entertainment Computing 1, 49-61.

Peng, W., Lin, J.-H. and Crouse, J. (2011). Is playing exergames really exercising? A meta-analysis of energy expenditure in active video games. Cyberpsychology, Behavior, and Social Networking, 681-688.

Rebsamen, S., Knols, R., Baschung, P., and de Bruin, E.D. (2019). Pfister, Exergame-driven High-Intensity Interval Training in untrained community dwelling older adults: A formative one group quasi-experimental feasibility trial. Frontiers in physiology 10, 1019.

Rheinberg, F., Vollmeyer, R. and Engeser (2003). S. Die erfassung des flow-erlebens.

Rhodes, R.E., Warburton, D.E. and Bredin, S.S. (2009). Predicting the effect of interactive video bikes on exercise adherence: An efficacy trial. Psychology, health & medicine 14, 631-640.

Rogers, K., & Weber, M. (2019). Audio Habits and Motivations in Video Game Players, Proceedings of the 14th International Audio Mostly Conference: A Journey in Sound on ZZZ, 2019, pp. 45-52.

Roy, M., Williams, S.M., Brown, R.C., Meredith-Jones, K.A., Osborne, H., Jospe, M. and Taylor, R.W. (2018). High-intensity interval training in the real world: outcomes from a 12-month intervention in overweight adults. Medicine & Science in Sports & Exercise 50, 1818-1826.

Salmon, J., Owen, N., Crawford, D., Bauman, A. and Sallis, J.F. (2003). Physical activity and sedentary behavior: a population-based study of barriers, enjoyment, and preference. Health psychology 22, 178.

Schaun, G.Z., & Del Vecchio, F.B. (2018). High-intensity interval exercises' acute impact on heart rate Variability: Comparison between whole-body and cycle ergometer protocols. The Journal of Strength & Conditioning Research 32, 223-229.

Shafer, D.M., Carbonara, C.P. and Popova, L. (2014). Controller required? The impact of natural mapping on interactivity, realism, presence, and enjoyment in motion-based video games. Presence: Teleoperators and Virtual Environments 23, 267-286.

Shaw, L.A., Wuensche, B.C., Lutteroth, C., Buckley, J. and Corballis, P. (2017). Evaluating sensory feedback for immersion in exergames, Proceedings of the Australasian Computer Science Week Multiconference, pp. 1-6.

Sinclair, J., Hingston, P. and Masek, M. (2009). Exergame development using the dual flow model, Proceedings of the Sixth Australasian Conference on Interactive Entertainment, 1-7.

Sinclair, J., Hingston, P. and Masek, M. (2007). Considerations for the design of exergames, Proceedings of the 5th international conference on Computer graphics and interactive techniques in Australia and Southeast Asia, pp. 289-295.
Steinbeck, K. S. (2001). The importance of physical activity in the prevention of overweight and obesity in childhood: a review and an opinion. *Obesity reviews*, *2*(2), 117-130.

Stojan, R., & Voelcker-Rehage, C. (2019). A systematic review on the cognitive benefits and neurophysiological correlates of exergaming in healthy older adults. Journal of clinical medicine 8, 734.

Tabata, I., Nishimura, K., Kouzaki, M., Hirai, Y., Ogita, F., Miyachi, M. and Yamamoto, K. (1996). Effects of moderate-intensity endurance and high-intensity intermittent training on anaerobic capacity and VO2max. Medicine & Science in Sports & Exercise 28, 1327-1330.

Teixeira, P.J., Carraça, E.V., Markland, D., Silva, M.N. and Ryan, R.M. (2012). Exercise, physical activity, and self-determination theory: a systematic review. International journal of behavioral nutrition and physical activity 9, 78.

Thompson, W. (2018). Worldwide survey of fitness trends for 2019. ACSM's Health Fit J, 22 (6): 10-7.

Thompson, W. R., Gordon, N.F. and Pescatello, L.S. (2010). ACSM's guidelines for exercise testing and prescription, Lippincott Williams & Wilkins.

Tondello, G.F., Mora, A., Marczewski, A. and Nacke, L.E. (2019). Empirical validation of the gamification user types hexad scale in English and Spanish. International Journal of Human-Computer Studies 127, 95-111.

Trost, S.G., Owen, N., Bauman, A.E., Sallis, J.F. and Brown, W. (2002). Correlates of adults' participation in physical activity: review and update. Medicine & science in sports & exercise 34, 1996-2001.

Turmo, L. V., Segura, E. M. and Waern, A. (2018). Movement correction in instructed fitness training: Design recommendations and opportunities, Proceedings of the 2018 Designing Interactive Systems Conference, pp. 1041-1054.

Valenzuela, T., Okubo, Y., Woodbury, A., Lord, S.R. and Delbaere, K. (2018). Adherence to technology-based exercise programs in older adults: a systematic review. Journal of Geriatric Physical Therapy 41, 49-61.

Wang, X., Ding, X., Su, S., Li, Z., Riese, H., Thayer, J. F., Treiber, F. and Snieder, H. (2009). Genetic influences on heart rate variability at rest and during stress. Psychophysiology 46, 458-465.

Weiss, T. Kreitinger, J., Wilde, H., Wiora, C., Steege, M., Dalleck, L. and Janot, J. (2010). Effect of functional resistance training on muscular fitness outcomes in young adults. Journal of Exercise Science & Fitness 8, 113-122.

Weston, K.S., Wisløff, U. and Coombes, J.S. (2014). High-intensity interval training in patients with lifestyle-induced cardiometabolic disease: a systematic review and meta-analysis. Br J Sports Med 48, 1227-1234.

Wharton, A., & Collins, K. (2011). Subjective measures of the influence of music customization on the video game play experience: A pilot study. Game Studies: the international journal of computer game research 11.

Wilke, J., Kaiser, S., Niederer, D., Kalo, K., Engeroff, T., Morath, C., Vogt, L. and Banzer, W. (2019). Effects of high-intensity functional circuit training on motor function and sport motivation in healthy, inactive adults. Scandinavian journal of medicine & science in sports 29, 144-153.
World Health Organization (2010): Global recommendations on physical activity for health.

Wüest, S., van de Langenberg, R. and de Bruin, E.D. (2014). Design considerations for a theory-driven exergame-based rehabilitation program to improve walking of persons with stroke. European Review of Aging and Physical Activity 11, 119-129.

Xiong, S., Zhang, P. and Gao, Z. (2019). Effects of Exergaming on Preschoolers' Executive Functions and Perceived Competence: A Pilot Randomized Trial. Journal of clinical medicine 8, 469.

Yogev-Seligmann, G., Rotem-Galili, Y., Mirelman, A., Dickstein, R., Giladi, M. and Hausdorff, J.M. (2010). How does explicit prioritization alter walking during dual-task performance? Effects of age and sex on gait speed and variability. Physical therapy 90, 177-186.

9 Conclusion

Today's widespread social tendency towards physical inactivity is being accompanied by a call for alternative, innovative methods that provide easy access and adherence to a physically active and healthy lifestyle. More than ten years ago, the gaming industry responded by introducing so-called exergames for the living room, followed by the fitness industry, which is now following suit with gamified workouts. Over the years, exergames started to establish themselves as promising, complementary, or alternative training devices.

The international and interdisciplinary research community has also been working on this promising trend for many years. Numerous studies have verified the potential of exergames to improve cognitive, physical, and mental health while providing a motivating and appealing experience in various target populations. At the same time, researchers and designers are still exploring new approaches to exploit the full potential of this innovative and enjoyable training method since evidence on long-term motivation and training effects is still very limited.

To contribute to the topic of attractive and effective exergames, this dissertation presented interdisciplinary R&D work aiming to provide reasonable and innovative explorations, valuable examples, and evaluations of attractive and effective exergame designs by following the six pre-defined main foci and the overall research question.

This chapter summarizes the contributions, discusses limitations as well as potential future work, and provides an outlook on ongoing R&D work based on the work and findings presented in this dissertation.

F1: Exploring the underlying, interdisciplinary theories and concepts of exergames

To capture the big picture, the topic of exergames was first approached from a theoretical perspective. Therefore, the underlying multidisciplinary theories and concepts of exergames from the fields of game design and human computer interaction, as well as psychology and sports science, were explored and analyzed in previous preliminary work.

Based on this, a preliminary generic framework was built (Martin & Wiemeyer, 2012a; Martin & Wiemeyer, 2012b). It framed various theories, concepts and findings on interactions and interdependencies between the player and his/her virtual avatar, the mediating game controller technology and the virtual and real, physical game/play space.
Subsequently, and on the basis of a continuous critical review of the growing body of related work on exergame design and research, the framework was further extended and continuously modified across the work presented in the different Manuscripts (I to VI) of the dissertation.

The final framework (Figure 1) was iterated to serve as both a theoretical scientific model as well as an applied exergame design and evaluation guideline for well-balanced attractive and effective exergames. Therefore, it transfers the theories, concepts, and findings into exergame design recommendations and sections them based on the three interdependent dimensions of an exergame: the player, the game controller, and the virtual game scenario. It further allocates every section to the overall categories of attractiveness and effectiveness.
Among other things, an attractive and effective exergame design encloses the player's moving and sensing single or social body (e.g., Bianchi-Berthouze et al., 2007; Mueller et al., 2011) and allows for effective and playful as well as interactive exercises (e.g., Marshall et al., 2016). These exercises in the "physical play space" in turn are mediated by the game-controller technology, which should be easily and naturally embedded into the moving player's body scheme (e.g., Kim et al., 2014; Pasch et al., 2009; Shafer et al., 2014) and potentially allow for social bodily interplay. Moreover, the virtual game scenario represents the player's single or social bodily input in the narrative and game mechanical frame of the

virtual environment and provides audio-visual as well as multi-sensory feedback for the player and their reacting body (e.g., Shaw et al., 2017).

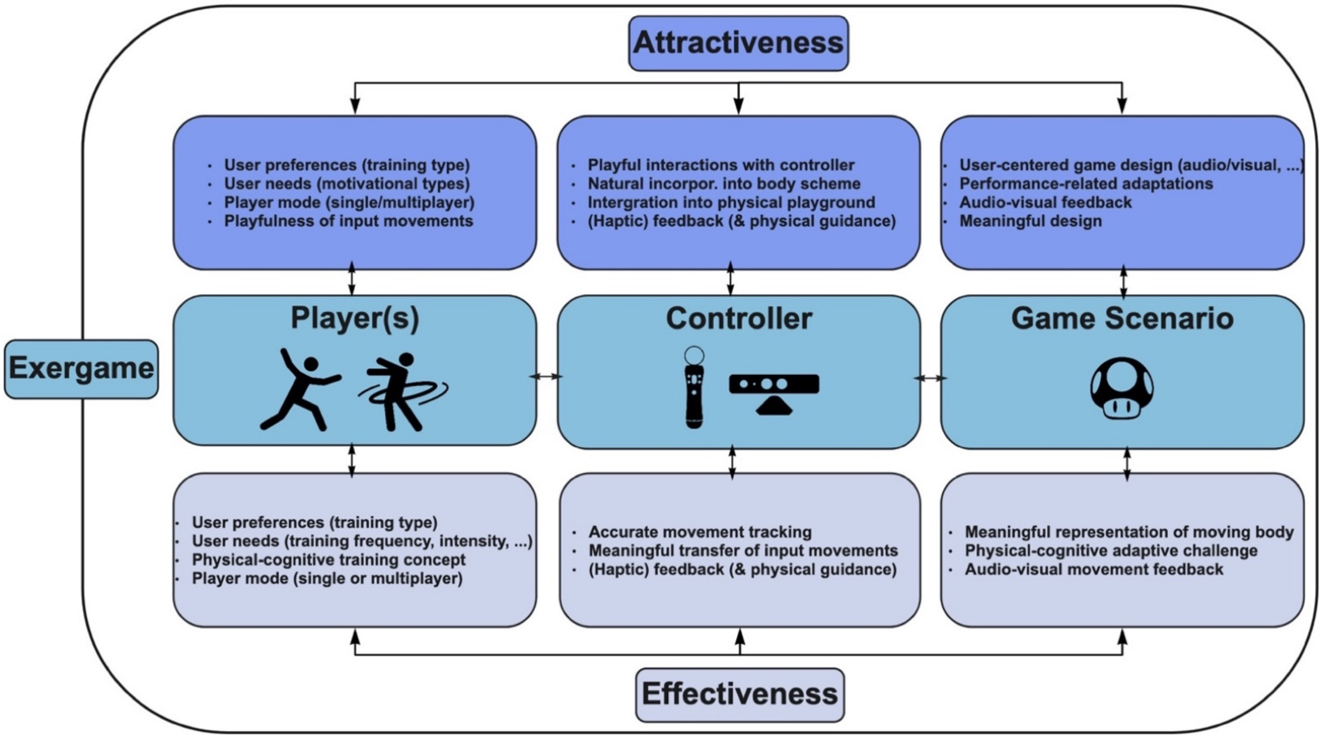

Figure 1: Overview of interdependent levels of attractive & effective exergames and theory-related recommendations for the design and evaluation of such exergames.

F2: Exploring interdisciplinary, user-centered exergame design and evaluation methods

Based on the establishment and iteration of the framework, the R&D work presented in this dissertation made it possible to define an iterative and multi-dimensional design and research process for attractive and effective exergames, which was applied and modified during the development and evaluations of Plunder Planet (Manuscript I to III) and the ExerCube (Manuscript IV to VI).
This contribution was important since at the time the presented work was conducted, no holistic design guidelines for attractive and effective exergames were available.

Theory-Based Design

Starting from a design perspective including all three dimensions of an exergame (player's body, controller technology and virtual game scenario), the presented exergame designs were always informed by theories, concepts, and findings from the interdisciplinary R&D community. This made it possible to start from a well-founded basis.

User-Centered Co-Design

An interdisciplinary collaboration of experts from the fields of game design and research (as concerns appealing audio-visual and narrative-based game and motivation design), as well as sports science (with regard to training principles and effective training concepts) further enriched the design process with expert knowledge from the respective fields and helped to balance the disciplinary standards and requirements to follow the double mission of exergames.
Furthermore, the involvement of primary (e.g., adults in a gym who will be playing the exergame as part of their workout routine) and secondary target groups (e.g., trainers who use the exergame to train their

customers) was essential to the exergame developments, since this allowed user needs and preferences of the respective target group to be equally covered.

Research-Based Design

Following this, an iterative design process further included continuous field and lab study phases on different levels of the development process. By applying interdisciplinary mixed methods from the fields of HCI (such as guideline-based interviews, participatory observations, research through design methods or surveys when analyzing gameplay experience and motion) and from movement science (such as physiological measurements (HR) or surveys when analyzing the physical effort or performance-related aspects), specific aspects of the (subjectively and/or objectively measured) attractiveness or the effectiveness of an exergame design could be properly tested. This helped to reflect the new concepts and designs and to identify blind spots in exergame design and research, which were then addressed in the further R&D work presented in the following sections.

The presented guideline can inform future exergame research and design for and with various target populations, and thus may contribute to the sustainable establishment of exergames on the market.

F3: Exploring the impact of different exergame controller technologies and input movements on player experience (attractiveness) and exergame intensity (effectiveness)

A specific focus of the work presented in this dissertation, was to explore and understand the impact of different exergame controller technologies and input movements on the gameplay experience and intensity in different exergames.

To better understand the theory-based assumption that the interposition of exergame technology brings specific transformations in the coupling of perception and action that do not occur in real sports situations (Martin & Wiemeyer, 2012a), Martin and Wiemeyer (2012b) analyzed second-generation commercial volleyball exergames (for the Microsoft Kinect and Sony Move sensor controller devices). Among other things, it was found that different controllers seemed to have different impacts on the gameplay experience of differently skilled players and that the implemented input movements were relatively sports-specific, and the controllers allowed for simplifications in the execution of the movements.

This preliminary exploratory phase helped to establish various avenues and practical approaches, which are discussed in this dissertation. Therefore, the theoretical and research-based knowledge was transferred into applied exergame design research – again covering all three interdependent dimensions (player, controller and game scenario) of the framework and following the multi-dimensional R&D process described above.

Based on this preliminary work, this dissertation presented two design and study cases (Manuscript I to VI) to further explore the impact of different controller technologies, and input movements on the player's gameplay experience with regard to the exergames' attractiveness and effectiveness:

Plunder Planet

Plunder Planet (Manuscript I to III) is an adaptive exergame environment, which was iteratively designed with and for children and allows a single- and cooperative multiplayer experience with two different controller devices.

On the bodily level, so far only some preliminary insights on sports specific movement input from experiments with the commercially available exergames were gained (Martin & Wiemeyer, 2012a; Martin & Wiemeyer, 2012b). Therefore, a cognitive-physical endurance training concept (coordinatively challenging moderate intensity) that also allowed for playful and free movements was developed to explore a more generalizable and holistic training concept.

In the previous pilot studies (Martin & Wiemeyer, 2012a; Martin & Wiemeyer, 2012b), experiments were made with the impact of two commercial controllers on the player's gameplay and spatial presence experience. Since there was no exergame available that enabled a full-body gameplay of the same game scenario with different controllers and thus, results of the preliminary evaluation were limited, two different motion-based controllers were designed and implemented with Plunder Planet (Manuscript I). The subjectively experienced attractiveness as well as the subjectively perceived and objectively measured effectiveness of the single player version of Plunder Planet with different controllers was compared and beside a generally great acceptance and good values, revealed different pros and cons of both devices for differently skilled players (trained in sports and/or gaming). The haptic full-body motion controller provided physical guidance and a cognitively and coordinatively challenging workout, which was better valued for experienced gamers with less athletic skills. The gesture-based Kinect sensor felt more natural, allowed for a greater freedom of movement, and provided a rather physically intense but cognitively less challenging workout, and was more highly rated by athletic players with less gameplay experience.
A preliminary exploratory analysis of the HR-values revealed a moderate training intensity (60-70% of HR_{max}).

The ExerCube
The ExerCube (Manuscript IV to VI) is a physically immersive and adaptive fitness game setting, which was iteratively designed with and for adults and allows cooperatively and competitive exergame experiences.
After a moderate training intensity could be verified with Plunder Planet, the aim was to explore a physical-cognitive training concept. Therefore, a coordinatively challenging functional workout protocol was designed that was scalable from moderate to high intensity and included several training stages (from a warm-up to the peak of the training) (Manuscript IV and VI).
Based on the findings regarding the impact of different controller devices with Plunder Planet, a mixed version of the advantages of both previously tested controllers that was proven as a well-accepted and appealing approach was explored.
Taking up first insights from the studies with Plunder Planet, it could be proved that the player's focus during the ExerCube session was more on the game than on the player's own body. Players experienced stronger physical exertion with the personal trainer and a stronger cognitive exertion with ExerCube.
On the level of the game scenario, further experiments were made with an adaptive audio design, which included adaptive sound and sound feedback, which were found to be promising and beneficial add-ons for a user-centered attractive exergame design.
A preliminary exploratory analysis of the HR-values revealed that over the full session HR ranged from 131bpm during the warm-up to 194bpm in the peak exercise level.

The R&D work presented in this section demonstrated the diverse impact of different controller technologies and movement inputs on players' subjectively experienced attractiveness and effectiveness while playing different exergame settings and shed light on the previously described necessity of a symbiotic and holistic design approach over all dimensions of an exergame.
However, there are also several limitations. Among other things, the studies were conducted with work-in-progress exergame prototypes. Therefore, the results provided preliminary, promising insights and indications for future, more in-depth R&D work rather than a finalized evaluation. Furthermore, the study designs had certain limitations such as the comparative between-subject design with Plunder Planet as well as a focus on single training sessions, which only allowed for explorations of the acute game experience and subjectively experienced effects of the exergame training. The long-term experience and effects remained unexplored.

F4: Exploring the impact of adaptive versus non-adaptive exergame designs on player experience (attractiveness) and exergame intensity (effectiveness)

Throughout the iterative R&D work presented in this dissertation, a topic of major interest was to explore the potential of physical-cognitive adaptive game mechanics and elements to further enhance the user-centered design, the balancing of fun and exertion of the exergames and, thus, the resulting gameplay and training experiences.
First, experiments with an exploratory adaption algorithm were conducted with Plunder Planet (Manuscript I). The implementation of this algorithm via trainer-UI made it possible to manually adapt the cognitive and the physical challenge of the exergame in real-time based on the player's fitness and gaming skills. It was very well received by the participants who reported great gameplay experiences. A preliminary exploration of participant's average HR revealed a tendency towards a moderate training intensity.
Based on this, the work presented in Manuscript II introduced and tested a detailed guide for the pre-classification and maintenance of the individual dual flow level, which was the result of the previously presented explorations and refinements of the physical-cognitive exergame adaption algorithm. A comparative study proved that a (well-balanced) adaptive version of the exergame was better valued than the non-adaptive version with regard to attractiveness (motivation, game flow, spatial presence experience, balance of cognitive and physical challenge) and enhanced the objective and subjective effectiveness (physical exertion (HR), balance of cognitive and physical challenge) for differently skilled players.

Building on the positively perceived adaptive gameplay with Plunder Planet, a refined and iterated version of the previously tested adaptive algorithm was implemented with the ExerCube and automated for the first time (Manuscript IV).
A comparative study again proved that the adaptive version had benefits with regard to subjectively experienced attractiveness (motivation, game flow, balance of cognitive and physical challenge) and subjectively experienced effectiveness (physical exertion, balance of cognitive and physical challenge). Moreover, some promising approaches for further iterations of the algorithm for different purposes (e.g., dual-domain training, multiplayer balancing, etc.) were identified.
A second study (Manuscript VI) with the redesigned prototype aimed to compare the objective and subjective physiological training intensity in the ExerCube to that induced by conventional functional HIIT. This study demonstrated that the ExerCube is a feasible tool for inducing functional HIIT intensity.

The presented work could prove, that an adaptive exergame design holds the potential to increase both attractiveness and effectiveness of an exergame. However, the presented work only focused on the evaluation of an algorithm including selected single physical and cognitive elements. Based on the promising findings of the presented work, the algorithm was already refined and extended with further parameters (e.g., movement accuracy, execution and acceleration as physical indicators or inhibition, memorization, divided attention and flexibility performance as cognitive indicators, as well as further mental parameters) as well as short- and long-term adaptations, which are and will be evaluated in future work.

F5: Exploring how different player modes influence player experience (attractiveness) and exergame intensity (effectiveness) in exergames

To tie up with findings from related work which identified a lack of well-balanced attractive and effective multiplayer exergames and which also criticized the body-centered design of controller technologies to be one main reason for that (Höök et al., 2016; Marquez Segura et al., 2013; Benford et al., 2005; Loke et al., 2007), another topic of interest of this thesis was to explore new exergame designs and different multiplayer settings (Manuscript III and V).
First, this topic was explored by comparing the experiences with Plunder Planet when it was played with two different controllers (haptic vs. gesture based) and as single or multiplayer version of the exergame

(Manuscript III). For the single player version, game experience and game flow were strongly related to previous experiences in sports and gaming. The Kinect was slightly preferred by athletic participants while the full-body motion controller received better ratings from non-athletic and/or gaming-experienced participants. These findings confirmed findings with the single player version from previous studies presented in Manuscript I and II.
Regarding social presence experience in the cooperative multiplayer version, the full-body motion controller was better ranked than the Kinect. The feeling of "empathy" was better, there were less "negative feelings" and more "engagement" with the full-body motion controller version. These results were further emphasized by the findings of the participatory observation which found that participants tended to be more interactive on the levels of interdependent bodily interplay and communication with the full-body motion controller version.
Besides the different impact of the two controller versions on players' social presence experience and their ability to serve as a social exertion "enabler", "supporter", and "shaper", both devices were found to generate slightly different experiences, as well as bodily interplay and communication strategies, which were further enhanced by players' individual gaming and sports skills and preferences.
These preliminary findings delivered first indications towards a new generation of exergame controller technology designs, which instead of "instrumentalizing" the body too much (Höök et al., 2016), narrowing the possibilities of movement and limiting or eliminating social dynamics (Marquez Segura et al., 2013; Benford et al., 2005; Loke et al., 2007), have the potential to "enable", "support" of "shape" them.

To take up the further important topic of different input movements and exergame effectiveness, which is closely related to the topic of controller devices (i.e., different controller devices allow for different input movement concepts), the work presented in Manuscript V further explored different full-body movement inputs by applying a research through design (RtD) method in the ExerCube. An embodied sketching activity with co-located cooperative and competitive multiplayer variations of the ExerCube game scenario was conducted, which allowed testing of new physical and social game mechanics.
The tested variations supported a rich training and social experience. It was shown that the majority of participants preferred collaborative modes of play because this encouraged communication and social interaction, and if with physical contact, was perceived as best balanced in fun and exertion. The competitive mode was preferred by the minority even though they were often experienced as physically challenging.

The potential of the RtD method presented in Manuscript V as well as the R&D work presented in Manuscript III were demonstrated to bring out some interesting design directions for well-balanced future social exergames. However, further R&D work is needed to prove these directions and indications and to derive more generalizable findings. Based on these promising findings, the use of the cooperative and competitive multiplayer version of the ExerCube will be explored in various settings and with different target populations.

F6: Comparing player experience (attractiveness) and intensity (effectiveness) of an adaptive exergame with a conventional training approach

To further contribute to the topic of exergames as demonstrably attractive and effective health-promoting training tools, and to address the need for more realistic and therefore field-related comparisons between exergames and conventional sports (Marshall and Linehan, 2020), the final aim of this dissertation was to compare the subjectively experienced and objectively measured effectiveness and attractiveness of a specifically designed exergame with a conventional training approach.
To elaborate on this topic, the ExerCube was chosen because it was the most likely to become a real training tool.
After the feasibility of the early-stage, the ExerCube concept was found to be well accepted by the target group and avenues for the further development of the immersive fitness game setting were established

(Martin-Niedecken & Mekler, 2018), the next iterative stage of the (yet work-in-progress) ExerCube design was compared with a functional training session with a personal training. The primary aim of this study (Manuscript IV) was to explore the subjectively experienced effectiveness and attractiveness of the ExerCube training to inform the further design of the exergame and to gain first indications as to whether it was possible to reach the targeted intensity (around 80 to 90% of HR_{max}) with the implemented training. Furthermore, the study was to test and inform the iteration of the exploratory physical-cognitive adaptation algorithm, which was automated in this study for the first time.

Since the preliminary comparative evaluation of the subjectively experienced effectiveness and attractiveness of an ExerCube session and a personal trainer session proved the general feasibility of the concept and revealed some early indications of the intensity of the ExerCube's training concept, the next step after another design iteration was to compare the objectively measured effectiveness of a single session with the ExerCube to a functional high-intensity interval training (fHIIT) with a personal trainer (Manuscript VI). Again, also the subjectively experienced attractiveness of both conditions was assessed. It could be shown that the ExerCube was a feasible tool for inducing fHIIT-level intensity. While physical exertion was slightly lower than in the conventional fHIIT condition, the ExerCube condition's average HR reached the fHIIT threshold, but yielded significantly better results for flow, enjoyment, and motivation. It also triggered higher cognitive load, i.e., it achieved dual-domain training. These results contribute empirical evidence that an exergame can be used to induce fHIIT-level intensity in addition to positive effects on motivation.

The presented studies delivered a valuable first impression of the actually measurable effectiveness of the ExerCube. However, the results only reflect acute effects of an exergame training. Future work needs to explore the long-term impact on both effectiveness and attractiveness.

Summary & Outlook

To sum up, this dissertation provides both research and design contributions to the promising field of exergames as attractive and effective training tools. Since this field is still relatively unexplored, the presented work creates a sound basis for future R&D work in this area.

However, the results of the presented R&D work must be seen more as an important, trend-setting first step towards attractive and effective exergame designs than as a comprehensive, self-contained work, as the presented studies still have some limitations. Among other things, only single-session comparative studies (mainly with the prototypical exergames) were conducted and no training intervention or longitudinal studies with bigger sample sizes and control groups were conducted. These will be needed to prove the demonstrated potential of long-term motivation, training adherence, and transferable training effects of the developed exergames.
However, for the purpose of the research-based development, it was necessary to investigate preliminary effects of the prototypical exergames on several design stages to allow for quick adaptations and optimizations of the multi-dimensional exergame designs.

Based on this findings, further studies with the refined ExerCube are and have been conducted already. A study in healthy adults could show that during a 25-minute activity in the ExerCube an average O_2 intake of 65% and an average HR_{max} of 87% were achieved (Ketelhut et al., 2020). The metabolic equivalent (MET) during the ExerCube session was also in the high-intensity range with 8.73. First results also show a positive effect on blood pressure and other hemodynamic parameters (central blood pressure, vascular elasticity) as well as on heart rate variability comparable to conventional endurance training. It was found that participants had significantly more fun during the training in the ExerCube than during a conventional endurance training.
In a recently completed study (Martin-Niedecken et al., unpublished work), the ExerCube has been tested in a 10-week training intervention with young athletes (ice hockey, soccer, floorball, handball).

A preliminary analysis of the results showed that an additional training with the ExerCube led to a significant improvement of single executive functions (flexibility, dual tasking and selective attention). The training experience, training motivation and enjoyment with the ExerCube were very well valued by participants even after multiple weeks of ExerCube trainings, which provides first indications for the ExerCube to be suitable as long-term motivating training device.

In another study it was investigated whether a standardized individually pre-assessed HR_{max} elicits different training intensities, training experiences and flow feelings in the ExerCube from the ExerCube using the formula-based pre-calculated HR_{max} in healthy young adults (Martin-Niedecken et al., 2021). No significant differences were found for HR parameters and perceived physical and cognitive exertion, or for overall flow feelings and physical activity enjoyment. Thus, the formula-based in-exergame adaptation approach was suitable in the presented study population and the ExerCube provided a reliable in-exergame adaptation and great exergame play experiences.

Another study in the field of work health promotion revealed that a work break via exergaming seems to potentially serve as a booster for the performance accuracy of cognitive flexibility in employees (Zwingmann, et al. 2020).

Through the work on embodied sketching activities with designers and 10 pairs of players which were presented in Manuscript V, a design space model as well as a novel design vocabulary including new bodily orientations in co-located physical interaction were derived (Marquez Segura et al., 2021).

Further studies are currently under way. Among other things, they focus on the evaluation of the optimal balance of cognitive and physical loads in an exergame, the comparison of different sound design conditions on performance acquisition in an exergame and the impact of different physical-cognitive training approaches on eSports athletes' cognitive and executive functioning, fine motor skills and eSports performance, as well as on the exploration of long-term effects and motivation in different target populations.

To conclude, besides some limitations, this dissertation showed that an interdisciplinary, research-based, iterative and multi-dimensional design process of attractive and effective exergames is a usable and beneficial approach to the establishment of exergames as additional or alternative training tools for giving a wide range of users easy access to a physically active lifestyle.

References

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

Bianchi-Berthouze, N., Kim, W.W., & Patel, D. (2007). Does body movement engage you more in digital game play? and why?. In *International conference on affective computing and intelligent interaction*. Springer, Berlin, Heidelberg, 102-113.

Höök, K., Jonsson, M.P. Ståhl, A. Mercurio, J. (2016). Somaesthetic Appreciation Design. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16), 3131-3142.

Ketelhut, S. , Martin-Niedecken, A.L., Kircher, E., Röglin, L., Ketelhut, R.G., Hottenrott, K., Ketelhut, K. (2020). Evaluating the exercise intensity during an exergame session in the ExerCube. ECSS Congress Sevilla 2020. Sevilla, ESP.

Kim, S.Y.S., Prestopnik, N., & Biocca, F. A. (2014). Body in the interactive game: How interface embodiment affects physical activity and health behavior change. *Computers in Human Behavior*, *36*, 376-384.

Loke, L., Larssen, A. T., Robertson, T., & Edwards, J. (2007). Understanding movement for interaction design: frameworks and approaches. *Personal and Ubiquitous Computing*, *11*(8), 691-701.

Márquez Segura, E., Waern, A., Moen, J., & Johansson, C. (2013). The design space of body games: technological, physical, and social design. In *Proceedings of the SIGCHI conference on Human Factors in computing systems,* 3365-3374.

Márquez Segura, E., Rogers, K., Martin-Niedecken, A.L., Niedecken, S., Turmo Vidal, L. (2021). Exploring the Design Space of Immersive Social Fitness Games: The ImSoFit Games Model. In CHI Conference on Human Factors in Computing Systems (CHI '21).

Martin, A.L. & Wiemeyer, J. (2012a). Technology-mediated experience of space while playing digital sports games. International Journal of Computer Science in Sport, 11 (Special Edition 1: Serious Games - Theory, Technology & Practice), pp. 135-146.

Martin, A.L. & Wiemeyer, J. (2012b). The Impact of Different Gaming Interfaces on Spatial Experience and Spatial Presence - A Pilot Study. In St. Göbel, J. Wiemeyer, B. Urban und Müller W. (Eds.). E-Learning and Games in Training, Education, Health and Sports. Springer Lecture Notes in Computer Science, GameDays 2012, pp. 177-182.

Martin-Niedecken, A.L., & Mekler, E.D. (2018). The ExerCube: Participatory Design of an Immersive Fitness Game Environment. In *Joint International Conference on Serious Games,* Springer, Cham, 263-275.

Martin-Niedecken, A. L., Schwarz, T., & Schättin, A. (2021). Comparing the Impact of Heart Rate-Based In-Game Adaptations in an Exergame-Based Functional High-Intensity Interval Training on Training Intensity and Experience in Healthy Young Adults. *Frontiers in Psychology*, *12*, 977.

Martin-Niedecken, A.L., Bucher, V., and Schättin, A. (unpublished work). Influence of a Ten-Week ExerCube Training On Executive Functions, Training Motivation, Enjoyment, and Mental Wellbeing in Young Athletes: A Non-Randomized Controlled Trial.

Marshall, J., Benford, S., & Pijnappel, S. (2016). Expanding exertion gaming. *International Journal of Human-Computer Studies*, *90*, 1-13.

Marshall, J., & Linehan, C. (2020). Are Exer-Games Exercise? A Scoping Review of the Short Term Effects of Exertion Games. *IEEE Transactions on Games*.

Mueller, F.F., Edge, D., Vetere, F., Gibbs, M.R., Agamanolis, S., Bongers, B., & Sheridan, J. G. (2011). Designing sports: a framework for exertion games. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* 2651-2660.

Shafer, D.M., Carbonara, C.P., & Popova, L. (2014). Controller required? The impact of natural mapping on interactivity, realism, presence, and enjoyment in motion-based video games. *Presence: Teleoperators and Virtual Environments*, *23*(3), 267-286.

Shaw, L.A., Wuensche, B.C., Lutteroth, C., Buckley, J., & Corballis, P. (2017). Evaluating sensory feedback for immersion in exergames. In *Proceedings of the Australasian Computer Science Week Multiconference,* 1-6.

Zwingmann, K., Martin-Niedecken, A. L., Schättin, A. and Voelcker-Rehage, C. (2020). Short physical-cognitive (work) breaks to improve cognitive flexibility via exergaming. ECSS Congress Sevilla 2020. Sevilla, ESP.

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11 List of Publications

Journal Publications

- **Martin-Niedecken, A.L.**, Schwarz, T. and Schättin, A. (2021). Comparing the Impact of Heart Rate-Based In-Game Adaptations in an Exergame-Based Functional High-Intensity Interval Training on Training Intensity and Experience in Healthy Young Adults. Frontiers in Psy., 12, 977, pp. 1-14.

- Ketelhut, S., Röglin, L., Kircher, E., **Martin-Niedecken, A.L.**, Ketelhut, R., Hottenrott, K. and Ketelhut, K. (2021). The New Way to Exercise? Evaluating an Innovative Heart-rate-controlled Exergame. International Journal of Sports Medicine 2021, 42, pp. 1–6.

- Schättin, A., Häfliger, St., Früh, B., Meyer, A., Böckler, S., Hungerbühler, Y., de Bruin, E.D., Frese, S., Steinlin Egli, R., Götz, U., Bauer, R., and **Martin-Niedecken, A.L.** (2021). Design and Evaluation of User-Centered Exergames for Multiple Sclerosis Patients: Multi-leveled Usability and Feasibility Studies. JMIR Serious Games, pp. 1-24.

- [Manuscript VI of this thesis] **Martin-Niedecken A.L.**, Mahrer, A., Rogers, K., De Bruin, E.D., and Schättin, A. (2020). «HIIT» the ExerCube: Comparing the Effectiveness of Functional High-Intensity Interval Training in Conventional vs. Exergame-Based Training. Frontiers in Comp. Sci., pp. 1-15.

- **Martin-Niedecken A.L.** and Schättin A. (2020) Let the Body'n'Brain Games Begin: Toward Innovative Training Approaches in eSports Athletes. Front. Psychol. 11, 138, pp. 1-9.

- McCaskey, M.A., Schättin, A., **Martin-Niedecken, A.L.**, and de Bruin, E.D. (2018). "Making More of IT: Enabling Intensive Motor Cognitive Rehabilitation Exercises in Geriatrics Using Information Technology Solutions," BioMed Research International, vol. 2018, Article ID 4856146, pp. 1-17.

- Florian "Floyd" Mueller, Josh Andres, Joe Marshall, Dag Svanæs, m. c. schraefel, Kathrin Gerling, Jakob Tholander, **Anna Lisa Martin-Niedecken**, Elena Márquez Segura, Elise van den Hoven, Nicholas Graham, Kristina Höök, and Corina Sas. 2018. Body-centric computing: results from a weeklong Dagstuhl seminar in a German castle. Interactions 25, 4 (June 2018), pp. 34-39.

- **Martin, A.L.**, Götz, U. & Bauer, R. (2014). "IMIC - Innovative Movement Therapies in Childhood". In Neurologie & Rehabilitation, Dettmers, C., Schönle, P.W., Weiller, C. (Eds.) and Wiemeyer, J. (Guest Ed.), 20th ed., vol. 4,, Hippocampus: Bad Honnef, pp. 2015-225.

- **Martin, A.L.** & Wiemeyer, J. (2012). Technology-mediated experience of space while playing digital sports games. International Journal of Computer Science in Sport, 11 (Special Edition 1: Serious Games - Theory, Technology & Practice), pp. 135-146.

Published Conference Papers and Contributions

- Márquez Segura, E., Rogers, K., **Martin-Niedecken, A.L.**, Niedecken, S., Turmo Vidal, L. (2021). Exploring the Design Space of Immersive Social Fitness Games: The ImSoFit Games Model. In Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (CHI '21), ACM, pp. 1-14.

- Kriglstein, S., **Martin-Niedecken, A.L.**, Turmo Vidal, L., Klarkowski, M., Rogers, K., Turkay, S., Seif El-Nasr, M., Marquez Segura, E., Drachen, A., and Perttu Hämäläinen (2021). Special Interest Group: The Present and Future of eSports in HCI. In CHI Conference on Human Factors in Computing Systems (CHI '21), ACM, pp. 1-4.

- Ketelhut, S. , **Martin-Niedecken, A.L.**, Kircher, E., Röglin, L., Ketelhut, R.G., Hottenrott, K., Ketelhut, K. (2020). Evaluating the exercise intensity during an exergame session in the ExerCube. ECSS Congress Sevilla 2020. Sevilla, ESP.

- Patibanda, R., Semertzidis, N., Scary, M., La Delfa, J., Andres, J., Baytaş, M.A., **Martin-Niedecken, A.L.**, et al. (2020). Motor Memory in CHI, In Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems. ACM, pp. 1-8.

- Zwingmann, K., **Martin-Niedecken, A. L.**, Schättin, A. and Voelcker-Rehage, C. (2020). Short physical-cognitive (work) breaks to improve cognitive flexibility via exergaming. ECSS Congress Sevilla 2020. Sevilla, ESP.

- [Manuscript V of this thesis] **Martin-Niedecken A.L.**, Márquez Segura E., Rogers K., Niedecken, S., and Turmo Vidal L. (2019). Towards Socially Immersive Fitness Games: An Exploratory Evaluation Through Embodied Sketching. In Proceedings of the Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts, ACM, pp. 525-534.

- [Manuscript IV of this thesis] **Martin-Niedecken A.L.**, Rogers K., Turmo Vidal L., Mekler E. D., and Márquez Segura E. (2019). ExerCube vs. Personal Trainer: Evaluating a Holistic, Immersive, and Adaptive Fitness Game Setup. In ACM Conference on Human Factors in Computing Systems Proceedings (CHI 2019), ACM, pp. 1-15.

- Kocher, M., **Martin-Niedecken, A.L.**, Li, Y., Kinzelbach, W., Wang, H., Bauer, R. and Lunin, L. (2019). “Save the Water” – A China Water Management Game Project. In Proceedings of the 3rd International GamiFIN Conference, GamiFIN 2019, Springer, pp. 1-12.

- Schmidt, M., Benzing, V., Bonadimann, P., **Martin-Niedecken, A.L.** (2019). Kognitiv-anspruchsvolle sportliche Aktivität und kognitive Leistung: Profitieren denkfaule Menschen weniger?. In: Proceedings der 11. SGS-Jahrestagung «Sport und Gehirn», Freiburg. CH.

- Schmidt, M., Benzing, V., Bonadimann, P., **Martin-Niedecken, A.L.** (2019). Cognitively engaging physical activity and cognitive performance: Is there a dose response relationship?. In: Proceedings of Health and Active Children, Verona, ITA.

- **Martin-Niedecken, A.L.**, & Mekler, E.D. (2018). The ExerCube: Participatory Design of an Immersive Fitness Game Environment. In *Joint International Conference on Serious Games,* Springer, Cham, pp. 263-275.

- [Manuscript III of this thesis] **Martin-Niedecken, A.L.** (2018). Designing for Bodily Interplay: Engaging with the Adaptive Social Exertion Game “Plunder Planet”. In Proceedings of the 17th ACM Conference on Interaction Design and Children (IDC'18), pp. 19-30.

- Kocher, M., Lunin, L., Kinzelbach, W., Bauer, R., Li, Y., Wang, H., and **Martin-Niedecken, A.L.** (2018). Save the Water! Serious Game for Water Management in Chinese Farmers. In Proceedings of 3rd Gamification and Serious Games Symposium (GSGS'18).

- Leu, A., **Martin-Niedecken, A.L.**, Wepf, H., Berger, F., Weber, A. & Frech, M. (2018). Serious Games für Young Carers. Digitale Spiele als Mediator zwischen Patienten, Angehörigen und Fachpersonen. Workshop-Abstract. *1. Nationaler Patientenkongress.* Bern, 14.09.2018.

- Kinzelbach, W., Li, Y., **Martin-Niedecken, A.L.**, Bauer, R., Lunin, L., Kocher, M. and Wang, H. (2018). Developing a board game for chinese farmers. In Geophysical Research Abstracts, Vol. 20, EGU2018-15336-1, EGU General Assembly 2018.

- **Martin-Niedecken, A.L.** & Götz, U. (2017). Go with the Dual Flow: Evaluating the Psychophysiological Adaptive Fitness Game Environment “Plunder Planet”. In Alcañiz M., Göbel S., Ma M., Fradinho Oliveira M., Baalsrud Hauge J., Marsh T. (Eds). Serious Games. JCSG 2017. Lecture Notes in Computer Science, vol. 10622, pp. 32-43.

- [Manuscript II of this thesis] **Martin-Niedecken, A.L.** (2017). Exploring Spatial Experiences of Children and Young Adolescents While Playing the Dual Flow-based Fitness Game “Plunder Planet”. In Proceedings of the International Conference on Computer-Human Interaction Research and Application (CHIRA '17), SCITEPRESS – Science and Technology Publications, pp. 218-229.

- **Martin-Niedecken, A.L.** (2017). Plunder Planet – A Psychophysiologically Adaptive Fitness Game Environment for Children and Young Adolescents. In Proceedings of the 2nd Gamification & Serious Game Symposium (GSGS '17).

- [Manuscript I of this thesis] **Martin-Niedecken, A.L.** & Götz, U. (2016). Design and Evaluation of a dynamically adaptive Fitness Game Environment for Children and Young Adolescents. In Proceedings of the ACM SIGCHI Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '16), pp. 205-212, ACM: New York, NY, USA.

- **Martin-Niedecken, A.L.**, Bauer, R., Mauerhofer, R. & Götz, U. (2015). RehabConnex - A Middleware for the Flexible Connection of Multimodal Game Applications with Input Devices used in Movement Therapy and Physical Exercising. In Proceedings of the 2015 IEEE Conference on Computational Intelligence and Games (CIG), IEEE Xplore Digital Library, pp. 496-502.

- **Martin-Niedecken, A.L.** (2015). Computer Games - Genres, Devices und deren (Transfer-) Effekte. In Könecke, Th., Preuß, H. & Schöllhorn, W. I. (Eds.), Moving Minds - Crossing Boundaries in Sport Science. In Abstracts of the 22. dvs Hochschultags in Mainz, Feldhaus: Edition Czwalina (Schriften der Deutschen Vereinigung für Sportwissenschaft: Band 251).

- **Martin, A.L.**, Götz, U. & Bauer, R. (2014). Development of Task-specific RehabGame Settings for Robot-assisted Pediatric Movement Therapies. In Proceedings of the 7th IEEE Consumer Electronics Society Games Media Entertainment Conference (GEM), IEEE Xplore Digital Library, pp. 1-4.

- **Martin, A.L.** & Kluckner, V.J. (2014). Player-centred Design Model for psychophysiological adaptive Exergame Fitness Training for Children. In Proceedings of the 4th Conference on Gaming and Playful Interaction in Healthcare, Schouten, B., Fedtke, S., Schijven, M., Vosmeer, M., Gekker, A. (Eds.), Springer Fachmedien: Wiesbaden, pp. 105-109.

- **Martin, A.L.**, Götz, U., Müller, C. & Bauer, R. (2014). "Gabarello v.1.0" and "Gabarello v.2.0": Development of motivating rehabilitation games for robot-assisted locomotion therapy in childhood. In Proceedings of the 4th Conference on Gaming and Playful Interaction in Healthcare, Schouten, B., Fedtke, S., Schijven, M., Vosmeer, M., Gekker, A. (Eds.), Springer Fachmedien: Wiesbaden, pp. 101-104.

- **Martin, A.L.** (2013). Exergames: One genre, many facets – Back to the Roots. In Filip Mess, F., Gruber, M. & Woll, A. (Eds.), „Sportwissenschaft grenzenlos?!“. Abstractband des 21. dvs-Hochschultag 2013 in Konstanz. Schriften der Deutschen Vereinigung für Sportwissenschaft: Band 230. Feldhaus: Edition Czwalina.

- **Martin, A.L.** & Wiemeyer, J. (2012). The Impact of Different Gaming Interfaces on Spatial Experience and Spatial Presence - A Pilot Study. In St. Göbel, J. Wiemeyer, B. Urban und Müller W.

(Eds.). E-Learning and Games in Training, Education, Health and Sports. Springer Lecture Notes in Computer Science, GameDays 2012, pp. 177-182.

- **Martin, A.L.** & Wiemeyer, J. (2011). Technisch vermittelte Raumerfahrungen beim Spielen digitaler Sportspiele. In Kähler, R.S. & Ziemainz, J. (Eds.), "Zukünftige Räume im Sport", Proceedings of the Annual Conference of the dvs-Kommission Sport und Raum, Christian-Albrecht-Universität zu Kiel. Schriften der Deutschen Vereinigung für Sportwissenschaft: Band 230. Feldhaus: Edition Czwalina, pp. 111-120.

- **Martin, A.L.** (2011). Interaktionen und Wechselwirkungen zwischen Mensch, Technik und Raum beim Spielen digitaler Sportspiele. In Heinen, T., Milek, A., Hohmann T. & Raab, M. (Hrsg.), Embodiment: Wahrnehmung - Kognition – Handlung. Abstractband der Tagung der dvs-Sektion Sportmotorik vom 20.-22. Januar 2011 in Köln, Deutsche Sporthochschule Köln. pp. 90-91.

Book Chapters

- Ketelhut, S., **Martin-Niedecken, A.L.**, Kubica, C., Nigg, C (2021). Stärkung physischer Leistungsressourcen im E-Sport. In Möckel, M. (Ed.). E-Sport Training: Lehrbuch für Trainerinnen und Trainer, Academia. ISBN 978-3-89665-960-6

- Dörner, R., **Martin-Niedecken, A.L.**, Kocher, M., Baranowski, T., Kickmeier-Rust, M., Göbel, S., Wiemeyer, J. & Gebelein, P. (2016). Contributing Disciplines. In Dörner, R., Göbel, S., Effelsberg, W. and Wiemeyer, J. (Eds.). Serious Games – Foundations, Concepts and Practice, Springerlink, pp. 35-55.

Books

- Göbel S, Caserman P, Hansen J, Bruder R, Abels S, Behrmann M, Hauge JB, Limpach O, Reichert M, Junge J, Vogt S, Raubold O, Nowarra N, Kruse R, Roller W, Streicher A, Walter T, Wacker M, Flory C, Hugo OA, Grimm P, Dörner R, Breitlauch L, Steinicke M, Bergmeyer W, Thiele-Schwez M, Althoff US, Wunsch H, Mildner P, Hofstaetter J, Kickmeier-Rust M, Rösch A, Schmoldt D, Stock R, Tackenberg S, Katzky U, Konrad R, Wiemeyer J, Kruse L, Hobmeier G, Herkersdorf M, Kalbe E, Brach M, Müller-Lietzkow J, Unger T, **Martin-Niedecken, A.L.** (2018). DIN SPEC 91380:2018-06 – Serious Games Metadata Format. 1. Ed, Berlin: Beuth Verlag.

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